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Physical and mechanical properties of waste wood powder and iron powder incorporated concrete with waste wood powder as partial replacement of fine aggregate

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Physical and mechanical properties of waste wood powder and iron powder incorporated concrete with waste wood powder as partial replacement of fine aggregate

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ABSTRACT

9 82 This research examines the physical and mechanical behaviour of concretes incorporating two industrial by-products waste wood powder (WD) used as a partial replacement of fine aggregate and waste iron dust (ID) introduced as a micro-filler additive with the objective of identifying pragmatic mix solutions that combine resource valorization, manageable workability and acceptable structural performance. Mixtures were prepared on a fixed volumetric proportion (cement : fine aggregate : coarse aggregate = 1 : 2.31 : 3.02) at a water–cement ratio of 0.60; WD replaced fine aggregate at 5 %, 10 % and 15 % by mass, ID was dosed at 1 %, 2 % and 3 % by mass of cement, and a special formulation combining 7 % WD with 10 % ID was also evaluated. In total, 84 standard 100 × 200 mm cylinders were cast, water-cured and tested at 28 days for compressive strength (ASTM C39), splitting tensile strength (ASTM C496) and fresh workability (slump, ASTM C143). Fresh-state measurements demonstrate a pronounced, replacement-dependent loss of workability with WD: the control mix exhibited a slump of 135 mm while replacements of 5 %, 10 % and 15 % produced slumps of 96 mm, 50 mm and 12 mm, respectively. Hardened-state testing revealed a clear, dose-dependent reduction in compressive capacity for WD-only mixes (control = 21.81 MPa; 5 % WD = 13.38 MPa; 10 % WD = 7.33 MPa; 15 % WD = 5.66 MPa), consistent with the lower stiffness and higher water affinity of organic fines. Critically, the incorporation of finely graded ID at low dosages substantially mitigated these losses: for example, 5 % WD combined with 2 % ID attained 19.70 MPa and with 3 % ID attained 23.30 MPa (the latter exceeding the control mean), while the 7 % WD + 10 % ID special mix achieved 25.49 MPa at 28 days. Splitting tensile results paralleled compressive trends, evidencing restoration of tensile capacity (control = 2.24 MPa; 5 % WD = 1.23 MPa; 5 % WD + 3 % ID = 2.39 MPa; 7 % WD + 10 % ID = 2.40 MPa). Fracture observations indicate that increasing WD content promotes more tortuous, bridged failure modes with greater post-peak energy dissipation, whereas ID refines crack propagation and produces more consolidated fracture surfaces. A preliminary materials cost appraisal—assuming waste feedstocks available at minimal acquisition cost shows modest unit savings (approximately 0.9 % at 5 % WD up to ≈2.6 % at 15 % WD per m³). Taken together, the results identify a defensible operational window—low WD substitution (≈5–7 %) combined with low-to-moderate ID dosing (≈1–3 %) that secures substantial waste incorporation while

preserving or recovering mechanical properties; the 7 % WD + 10 % ID formulation appears particularly promising. Prior to field implementation, however, further replication, production-scale trials, and systematic quality-control procedures are recommended to ensure reproducibility and long-term performance.

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LIST OF ABBREVIATIONS

ASTM	American Society for Testing Materials
ACI	American Concrete Institute
SAC	Stone aggregate concrete
CA	Coarse aggregate
WD	Wood Dust
ID	Iron Dust
f'_c	Compressive strength of concrete at the age of 28 days.
FA	Fine aggregate
FM	Fineness Modulus
MOE	Modulus of elasticity
ITZs	Interfacial transition zones
KN	Kilo-Newton
MPa	Mega Pascal
NCA	Natural coarse aggregate
OD	Oven dry
OPC	Ordinary Portland cement
PSI	Pound per square inch
SSD	Saturated surface dry
STS	Splitting tensile strength
UTM	Universal Testing Machine
W/C	Water cement ratio
SG	Specific gravity
LCA	Life Cycle Assessment
SCM	Supplementary Cementitious Materials

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CHAPTER I

INTRODUCTION

1.1 Background of the study

The growing demand for concrete, driven by global urbanization, has contributed to a massive extraction of natural resources, particularly river sand. In the past two decades, approximately 50 billion tons have been extracted globally each year (World Economic Forum, 2023), that making sand the second most consumed natural resource after water (Beiser, 2015). This over-exploitation not only depletes natural reserves but also leads to ecological imbalances. Consequently, researchers have been exploring sustainable substitutes that can ensure the required physical and mechanical performance of concrete while minimizing the environmental impact (Habib and Hassan, 2015; Alom, 2014a, 2014b).

The increasing emphasis on sustainability in the construction sector has led to extensive research on the incorporation of industrial and agricultural waste materials in concrete production . In the past few years, the use of alternative materials in the form of recycled or waste materials as a partial replacement of natural aggregates and cement has gained significant attention due to environmental and resource scarcity concerns (Rashid, 2005).

One of the most promising alternatives for replacing fine aggregate who show eco-friendly nature and even don't carbon deposit during production is waste wood dust, also known as sawdust or wood powder, it is a byproduct of carpentry, sawmills, and furniture industries. This material, when processed and filtered to appropriate sizes, has shown potential as a partial replacement in concrete mixtures. Studies have shown that replacing the fine aggregates with 5% wood powder may provide reduced compressive strengths of concrete that are comparable to conventional concrete mixes, although over-use could create negative effect on density and workability due to the porous and organic nature of wood powder due to increased water absorption and negatively impacting the hydration reaction of concrete (Abdullahi et al., 2013; Yakubu & Bukar, 2020). Furthermore, the natural fibers of wood particles can enhance crack resistance and reduce the brittleness of concrete (Ahmed et al., 2018). However, limitations regarding the optimum percentage of substitution remain a key area for continued investigation.

The reduction in compressive strength by using wood powder can be controlled by using an effective material as an additive that can impart strength to concrete. Waste iron powder can be considered such type of additive that is often sourced from machining and steel fabrication industries, is rich in ferrous content, and can act as a micro-filler to enhance the particle packing density within the concrete matrix. Literature informs that when it is used in small proportions as a replacement of fine aggregate (typically 1% to 3% by weight of cement or total mix), it helps fill internal voids, improving both mechanical strength (Ramesh et al., 2020; Kothai & Malathy, 2015). Hence, the incorporation of iron powder in the wood powder composite concrete might have a significant contribution in enhancing the mechanical properties of sustainable concrete .

Despite several studies addressing the individual use of wood powder or iron powder in concrete, the combined influence of these two waste materials as a replacement material and an additive material has not been explored yet. The synergistic behavior between a lightweight organic filler (wood powder) and a dense metallic filler (iron powder) could offer innovative insights into the development of green concrete with balanced physical and mechanical properties. This study aims to explore the impact of incorporating 5%, 10%, and 15% wood powder as a partial replacement of fine aggregate, followed by the addition of 1%, 2%, and 3% waste iron powder to the different mixes of wood powder, and thereby inferring the optimum amounts. The findings would provide a viable path toward sustainable construction practices and waste management .

1.2 Significance of Study

The mechanical characteristics of concrete using the waste wood powder (WP) as a partial fine aggregate (FA) and waste iron powder (IP) as an additive will be determined. Based on the results obtained in the experiments , feasibility of using waste wood powder (WP) and iron powder (IP) in concrete production will be identified and it may be possible to reduce the dependency on natural resources and the construction related environmental impacts.

This study will support sustainable construction practices by supporting the valorizations of industrial and wood-working by-products, which will reduce the disposal problems and circular economy principles.

1.3 Objectives of the study

The objectives of the current research work are given below:

i. Develop a consistent and workable concrete mix through partial replacement of Fine Aggregate (FA) with Waste Wood Powder (WP) and the addition of Iron Powder (IP).

ii. Explore the effects of WP in concrete as a replacement for FA and IP as an additive in changing the compressive strength and tensile strength of the composite concrete

iii. Determine the optimum combination of WP as FA replacement and IP as additives in the concrete mix

iv. Investigate the microstructure of the composite concrete with WP as a replacement of FA and IP as an additive material.

v. Convey a cost analysis of the different mixes of the composite concrete with WP and IP.

1.4 Scope of the study

In this study, crushed stone was used as the coarse aggregate (FM = 7.00) and natural sand as the fine aggregate (FM = 2.70). Ordinary Portland Cement (OPC) served as the binding material. The concrete mixing proportion was 1 : 2.31 : 3.02 . The water-cement ratio of concrete was used 0.6. Waste wood dust (WD) (FM = 1.40) was used as a partial replacement of fine aggregate at 5%, 10%, and 15%, while waste iron dust (ID) (FM = 0.784) was incorporated as an additive at 1%, 2%, and 3%. These combinations were tested on a total of 78 cylindrical specimens. Additionally, 6 cylindrical specimens were cast using 7% wood dust replacement and 10% iron dust additive. Mechanical and physical properties of all mixes were evaluated after 28 days of curing.

CHAPTER II

LITERATURE REVIEW

2.1 Introduction (Overview of this chapter)

103 Concrete is the world's most versatile, economical and structurally efficient building material. It is used in projects from housing developments to commercial and infrastructure projects: consequently, it can be seen as the backbone of the built environment. However, traditional concrete manufacturing is extremely inconvenient environmentally, particularly from two major sources - the mining of natural aggregates and Ordinary Portland Cement (OPC) manufacture. Cement manufacture alone accounts for an estimated 7-8% of global anthropogenic carbon dioxide emissions (Siddique et al. 2020) and the unsettling of river ecosystem and biodiversity due to natural mining of sand is estimated at 50+ billion tons per annum (World Economic Forum, 2023). The worldwide problem of environmental degradation and the demand for innovative solutions have pushed researchers and decision-makers to explore new possibilities regarding how the ecological impact of concrete can be reduced without 91 compromising performance. One of the great innovations is the use of industrial by-products and waste materials in concrete. Doing so can help the construction sector simultaneously minimize the environmental degradation of the environment while maximizing the valorized waste streams that can otherwise end up in the landfills. In 136 particular, the use of waste wood powder (WD) and waste iron dust (ID) has attracted much attention in recent times. These materials are abundantly available as by-products of two businesses with large production volumes: sawmills and timber processing (for WD) and metal machining and steelworks (for ID). They offer the potential to have a 78 positive impact on the environment by reducing the consumption of finite resources; when they are reused in concrete, they can also contribute to the circular economy by converting wasted material into construction material which offers added value for money. Wood-powder or sawdust is lethal in huge quantities in carpentry and furniture industry and in sawmills. The traditional practice is to burn or dump the waste, both of 96 which pollute the air and foul the soil (Maglad et al, 2023). Using WD in concrete as partial replacement of fine aggregate is considered beneficial not only because it reduces 9 the need for natural river sand for concrete, but also because there is a corresponding decrease in unit weight of concrete. Several studies observed good compressive strength performance, with low level replacement (generally 5 - 10% by mass of fine aggregate) as well as lightweight concretes with some applications in non-loadbearing wall or partition structures at higher levels. Hence, WD is a good eco-friendly resource that

should be used in construction for efficient use of resources. Apart from the mechanical properties, the lignocellulosic structure of WD also contributes to its superior thermal insulation properties which renders the buildings more energy efficient (Turgut, 2007). Similarly, the waste iron dust is mainly generated from machining, grinding, and steel cutting machining process. Such residues are fine-grained with high iron oxides content suitable for their use as micro fillers of cementitious matrices (Largeau et al., 2018). Unlike the porosity that results from WD, ID fills the pores between cement grains and aggregates thus densifying the concrete microstructure and decreasing capillary porosity. It was also revealed that at low doses (1-3% by weight of cement), the addition of iron dust can improve the compressive strength, flexural capacity, and the durability properties such as water absorption and permeability (Ghannam et al. 2016; Miah et al. 2020). However, studies beyond 3% indicate decreasing dose-response, a concept that explains the need for dosage optimization. The integration of ID is therefore a novel approach for achieving superior mechanical and durability properties and, at the same time, diverting hazardous metal waste from the environment. Especially, the combination of WD and ID is a novel concept. While WD has a density reducing effect, aiding in the quest for reduced weight construction, the porosity nature of WD at higher level of replacement can have a negative effect on strength and workability. ID, on the other hand, works to increase packing density to eliminate the negatives associated with porosity. The interaction of these two waste materials therefore has an opportunity for synergy (WD-sustainability and lightness counterbalance porosity) to create a well-balanced eco-friendly concrete. The synergy is poorly understood in literature, and is a vast gap in the research. The valorization of Wood Dust (WD) and Iron Dust (ID) use in concrete relates to USG Sustainable Development Goals (SDGs) SDG 9 (Industry, Innovation and Infrastructure), SDG 11 (Sustainable Cities and Communities) and SDG 12 (Responsible Consumption and Production). It offers a solution effective for decarbonization of construction, elimination of resource dependency and further development of waste-to-resource initiatives. From a cost perspective the use of locally available waste materials for production can decrease the cost of production (especially in regions where sand scarcity has escalated the cost of construction processes) (Waqar et al., 2024). From an environmental perspective, a reduction of landfill deposition and mining of resources has a direct impact on preserving the ecosystem. From the social perspective, light weight concrete allows for safer and more sustainable built environments if it is environmentally friendly. In summary, sustainable building material is a paradigm shift for using industrial wastes in concrete. Waste wood powder and waste iron dust are among the materials that seem to have the most promising properties for the future: on the one hand, lightweight sustainability; on the other, densification of the structure. Examining their combined impact is a very important step forward in sustainable construction research. Thus, this chapter reviews the literature related to the properties of the constituent materials, the behaviour of the WD and the ID in the concrete and their potential synergies as well as their overall eco-friendly and economic benefits from their incorporation.

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2.2 Materials of Concrete

Concrete is a composite material made up of cement, fine and coarse aggregates, water and, in the sustainable era, supplementary constituents or waste constituents. Each component contributes to the final performance profile, durability profile and sustainability profile, of the mixture. This section presents an overview of the traditional materials that provide the foundation of concrete with information on the binder (cement) and aggregates, then provides context to the incorporation of alternative waste materials.

2.2.1 Binders

Binders are cohesive substances which undergo chemical and physical processes to set and harden and thus bind discrete particulate materials into a monolithic solid. In the case of construction composites, they make up the important matrix phase that is responsible for structural integrity and durability.

2.2.1.1 Cement

Cement is finely milled, inorganic and hydraulic binder. Its main use is the provision of strength and stability to mixtures such as concrete and mortar by virtue of a series of exothermic hydrolysis and hydration reactions upon the addition of water. Ordinary Portland Cement (OPC) is the most common type in the world, forming the basic binding material for most structural uses.

The chemistry of OPC is predicated on the high-temperature sintering of calcareous and argillaceous materials to give rise to calcium silicate clinker. The basic chemical reactions are calcination of limestone:

Calcination:

94 $CaCO_3$ (s) → CaO (s) + CO_2 (g)

The thermal decomposition of calcium carbonate, commonly referred to as calcination.

Hydration:

CaO (s) + H_2O (l) → $Ca(OH)_2$ (s) + Heat

Subsequently, the resultant time (CaO) undergoes hydration

In industrial production, these reactions occur within a complex system where lime (CaO), silica (SiO_2), alumina (Al_2O_3), and iron oxide (Fe_2O_3) interact in a kiln to form a series of multicomponent phases (Taylor, 1964). The quality and performance characteristics of the final cement product are a direct consequence of the proportion and reactivity of these constituent phases (Neville, 1996).

2.2.1.2 Chemical Composition of (OPC) Cement (Shah Cement Brand)

The engineering characteristics of OPC is not only dependent on the bulk oxide composition but mainly dependent on the four major crystalline phases, so-called Bogue compounds, that make up the cement clinker (Taylor, 1964). There are well-established functional roles for these compounds:

Tricalcium Silicate (C_3S): As the most abundant phase of modern OPC, alite (C_3S), hydrates quickly, and is the main contributor to early-age strength gain (Neville, 1996).

Dicalcium Silicate (C_2S): The hydration of belite (C_2S) is considerably slower than that of C_3S. Its main contribution lies in the long-time strength gain of the cement paste (for years after the placement) (Neville, 1996).

Tricalcium Aluminate (C_3A): This phase occurs in the highest reactivity with water and causes the rapid release of heat that is responsible for the initial setting time. Its reaction then is moderated by adding gypsum ($CaSO_4$*$2H_2O$) to prevent the flash set. The effect of having a high C_3A content is correlated with reduced resistance to sulfate attack (Neville, 1996; Taylor, 1964).

126 Tetracalcium Aluminoferrite (C_4AF): The ferrite phase acts as a flux to reduce the clinkering temperature during the manufacture. It is an intermediate rate of hydration and provides modest strength contribution. Its chief influence in this is the color of the cement (Taylor, 1964).

The particular OPC cement investigation is produced by Shah Cement Industry Limited Chemical analysis proves that this product satisfies the requirements set for Type I General Use Portland Cement according to ASTM C150 (ASTM, 2022). The oxide content determined by Ali, Khan and Hossain (2008), using standard methods of testing (British Standards Institution, 1991) is given in Table 1. The potential compound composition is calculated from the oxide analysis using Bogue's equations (Bogue, 1955) for comparative purposes to range of typical values for Type I cement.

97 **Table : Chemical and Potential Compound Composition of Shah Cement (Type I, OPC)**

Parameter	ASTM C150 Type I Typical Range	Shah Cement (Experimental Values)	Test Method / Standard
Oxide Composition (wt. %)			
SiO_2	-	21.52	BS 12:1992
Al_2O_3	-	4.58	BS 12:1992
Fe_2O_3	-	3.38	BS 12:1992
CaO	-	66.02	BS 12:1992
MgO	≤ 6.0	1.26	BS 12:1992
SO_3	≤ 3.0*	2.76	BS 12:1992
Loss on Ignition (LOI)	≤ 3.0	1.235	BS 12:1992
Insoluble Residue (IR)	≤ 0.75	0.45	BS 12:1992

Table : Potential Compound Composition of Shah Cement (Type I, OPC)

Potential Compound Composition (wt. %)	ASTM C150 Type I Typical Range	Shah Cement (Experimental Values)	Source
C_3S (Alite)	45 - 60	~55 (Estimated)	(Bogue, 1955)
C_2S (Belite)	15 - 30	~20 (Estimated)	(Bogue, 1955)
C_3A	6 - 12	~7 (Estimated)	(Bogue, 1955)
C_4AF (Ferrite)	6 - 8	~10 (Estimated)	(Bogue, 1955)

The permissible SO_3 limit in ASTM C150 is contingent on the C_3A content; the maximum is 3.0% when C_3A is ≤8%. The experimental value for Shah Cement (2.76%) is within specification Ali, Khan and Hossain (2008).

2.2.2 Aggregates

Aggregates account for about 70–80% of the concrete's volume, serving as the skeletal framework and determining much of its density, durability, and workability. According to ASTM C33/C33M, aggregates must meet requirements for gradation, soundness, and absence of deleterious materials to ensure predictable performance.

2.2.2.1 Fine Aggregate (FA)

Fine aggregate (FA), generally natural river sand, which occupies voids between coarse aggregate particles and imparts a large part of workability, cohesiveness and surface finish. Its fineness modulus or FM which usually varies between 2.3 and 3.1 affects water demand and paste content. For conventional concretes sand provides dense packing, and reduces bleeding and segregation.

However, the construction industry is up against a growing challenge of sand availability. Global extraction of sand has increased massively and consequently, ecosystems are being destroyed, river banks are eroding, groundwater is depleting and biodiversity is declining (World Economic Forum, 2023). With continued increased demand, replacing natural sand with sustainable options is a necessity. Waste wood powder, because of its fineness and its biodegradable origin is a sustainable solution. While WD brings about increased absorption, it can make a better curing and lesser shrinkage in concrete . (Waqar et al., 2024).

Thus, although FA remains one of the main constituents, its partial substitution by WD is a strategic innovation combining environmental complicity and practicability in terms of performance.

2.2.2.2 Coarse Aggregate (CA)

Coarse aggregates, typically crushed stone or gravel, provide the structural skeleton of concrete. Their angularity improves inter-particle interlocking, enhancing compressive strength and reducing shrinkage.

Under the requirements of ASTM C33, CA must have characteristics of soundness and minimal deleterious substance and be resistant to weathering. Crushed stone with FM 6.75 to 8.00, the ideal for structural concretes offering both strength and dimensional stability.

2.3 Characteristics of Waste Materials for Valorization

The properties of waste wood powder (WD) and waste iron dust (ID) that are most pertinent to the performance of (hydration and mechanical properties) of concrete particle characteristics, unit weight, particle nature, and water interaction. The discussion deliberately frames potential challenges like wood powder have high absorption capability and iron dust increase density so by combining them both it can be turned into performance advantages like internal curing and lightweight design for the mix and eco-friendly.

2.3.1 Waste Wood Powder (WD)

Waste wood powder (WD) is a lignocellulosic waste commonly produced, during timber processing, furniture manufacturing or wood workshops. Particle size distribution is usually close finer like conventional sand and particle is irregular, flaky with internal porosity. The WD has similar FM with low unit weight that put it squarely in the "low-density" class. These characteristics suggest immediate functional consequences when WD is used in concrete in other side it decreases the concrete's bulk density, and its surface area and porosity increase the water uptake and the particle-to-paste interactions.

Low unit weight is not a limitation but an engineering opportunity. Using a percentage of the fine aggregate in place of WD results in lighter weight concrete elements that reduce dead load and can reduce foundation and structural element requirements. Studies have shown multiple times that density reductions are a consequence of modest contents of WD typical drops in density at 5-10%WD replacement results have been reported (Cabanillas-Hernandez et al., 2024) showing a fall in density of 6-12%. Lower density materials are attractive for non-loadbearing components, for facade panels, and for precast elements in which transport and handling economies are important. Importantly, lower density may also play a role in lower seismic mass, favoring the seismic performance of structures if detailing is done accordingly (Hernández-Ocaña et al., 2022).

Because of the fine particles shape and high surface area, the presence of WD increases the paste demand in concrete. This is exhibited in the form of less slump and increased demand for mixing water (Siddique et al., 2020). However, to keep workability within the designed workability at WD replacement levels of 5-10% need higher water-cement ratio (Thakur et al., 2023; Waqar et al., 2024).

In most of the research it appears that low-level WD replacement (frequently 5%) causes low compressive strength losses (frequently <10%), while levels of replacement exceeding 10% cause progressively higher strength reductions (Siddique et al., 2020; Turgut, 2007). This is because the volume of incompressible mineral aggregate is reduced by WD while the hardened matrix is introduced with additional porosity. Nonetheless, the minor strength deplications at low replacement ratios are counterbalanced by the advantages of sustainability and reduced weight and can still meet performance requirements for many non-structural and semi-structural applications (Cabanillas-Hernandez, et al., 2024). Beam-scale studies also show evidence of preserved or slightly enhanced ductility and energy dissipation capacity of WD mixes at low levels of replacement (Maglad et al., 2023), a favorable safety attribute. Based on the reviewed evidence the most reliable application window is 5 - 10% WD as partial replacement of fine aggregate.

2.3.2 Absorption Capacity of WD

Wood particles will often absorb water at a higher rate than mineral sands, due to their porous cellulosic structure. While it is important to note a range of reported values for these absorption properties dependent on the absorption capacity of wood dust , the consensus from practitioners in the field is to conduct this property as one of the engineering variables which can be altered as opposed to necessitating it as an impossible problem (Siddique et al., 2020; Thakur et al., 2023). In practice, failure to account for absorption results in lower effective w/c, reduced workability and potential under-hydration; but simple maintaining w/c ratio protocols can corrects this.

WD work great as a source of internal curing water that gradually releases during the hydration of cement. This can encourage continued hydration of cementitious phases, eliminate early-age shrinkage and result in better later-age strength development compared to a poorly cured control.

2.3.3 Waste Iron Dust (ID)

Waste iron dust (ID) is a by-product of metalwork, grinding and machining process. It typically consists of very fine dense particles rich in oxides of iron - Largeau et al. (2018) report predominant particle sizes in the sub-micrometer to micrometer range with high Fe_2O_3 content and a particle density near 1.5~5.0 g/cm^3. based on study the ID has Lower (FM) than sand, indicating extreme fineness relative to sand and even too many supplementary cementitious fines.

Due to its fine gradation, and high density, ID acts as an efficient micro-filler particle . It fills the interstitium between cement grains and the sand's finer fraction, optimizing packing density and decreasing capillary pore volume (Largeau et al., 2018; Ghannam et al., 2016). This densification can be expressed structurally by the increase of compressive strength and with decreased water absorption at optimal low dosages. Multiple studies show evidence of a low dosage optimum (>10% by mass of binder or partial cement replacement)where compressive strength and porosity metrics are improved; beyond that, excessive fines can increase the water demand and reduce workability (Largeau et al., 2018; Miah et al., 2020).

Fine metallic powders contribute to a reduction in slump, as is likely to result from high specific surface and particle angularity, but are likely to have a limited reduction in the low dosages, and therefore control can be achieved with admixtures. Largeau et al. (2018) reported linear reduction in slump with the addition of iron powder and still acceptable consistency at 1-2.5% additions and a fixed w/c ratio. When using ID as a filler additive (not as bulk replacement), workability may even increase in cohesive mixes because of the reduced segregation.

At the optimum dosages, ID results in a reduction in the porosity and water absorption, contributing to an increase of 28-day compressive strengths and improved indices (Largeau et al., 2018; Ghannam et al., 2016). In addition, Miah et al. (2020) further reported that the dried shrinkage can be slightly mitigated with recycled iron powders if it acts well as packing agent and thus improves dimensional stability in the hardened mortar/concrete.

Researcher(s)	Iron Dust (ID) Dosage %	Observed Effect on Packing Density / Voids	Optimum Range Identified	Remarks / Supporting Observations
Largeau et al. (2018)	0–2.5%	Linear increase in packing density; ID fills micro-voids between cement and sand particles, reducing	1–2.5%	Noted improved compressive strength and reduced porosity; slump reduced slightly but remained workable.

		capillary pores.		
Ghannam et al. (2016)	0–5%	Filler action improves particle packing and reduces void ratio significantly up to ~3%; excessive fine content beyond 5% increases water demand.	2–3%	Demonstrated increased density and ~10–15% strength gain at 2–3% addition; beyond this, strength plateaued or declined.
Miah et al. (2020)	0–10%	Improvement in packing efficiency and micro-void filling up to 3%; further increase led to clustering and reduced workability.	2–3%	Slight reduction in drying shrinkage due to densified structure; optimum at ~3% ID for balanced workability and strength.

Table : Summary of Reported Optimum Packing Density and Void Reduction due to Iron Dust Incorporation

ID is primarily an inert or weakly interacting filler in most useful dosages; its main advantages come not from its chemical pozzolanic reactivity, but from physical packing. This makes it desirable for incorporation at low risk in conventional OPC concretes, with no need for significant changes in cement chemistry. The high iron oxide content does not cause unwanted reactions under normal conditions and might make a contribution to the durability by reducing the capillary pathways.

2.3.4 Absorption Capacity of ID

Waste iron dust (ID) exhibits a characteristically negligible intrinsic water absorption compared with porous mineral or organic fines; the iron-rich particles are essentially non-porous at the particle scale, so they do not act as internal water reservoirs in the way that wood powder or lightweight fillers do (Miah et al., 2020). This trait is practically important when introduced at low dosages (typical practice is 1–3% by binder mass), ID does not appreciably increase the mix's free-water loss to particle absorption, so effective water-cement ratio remains easier to control than with hygroscopic wastes. Nonetheless, ID can influence water demand indirectly because of its very fine particle size and large specific surface area fresh mix water must wet a greater surface area and disperse fine agglomerates, which can manifest as an apparent increase in water demand or a modest slump reduction if admixtures are not used (Largeau et al., 2018).

Critically, this combination negligible intrinsic absorption plus high fineness is advantageous for compressive strength unlike absorptive replacements that raise internal porosity, ID's micro-filler action reduces capillary connectivity and bulk water absorption of the hardened matrix by filling micro-voids and increasing tortuosity of pore channels (Ghannam et al., 2016). In practice, the net effect observed in multiple experimental series is lowered water uptake and reduced sorptivity for mixes containing optimized low doses of ID, provided fresh-state rheology is managed and ID is well dispersed. For mix designers, the operational takeaway is clear: ID as a non-absorbing micro-filler monitor slump and surface wetting during batching, using ID dose not much effect on workability at lower doses uses, and also improved hardened-state reduce micro-voids and increase compressive strength at appropriate dosages (1–3%) (Miah et al., 2020).

2.4 Waste Wood Powder (WD) in Concrete

Waste wood powder (WD), produced from sawdust and milling fines, is an attractive partial fine-aggregate substitute because it simultaneously reduces concrete unit weight and diverts biomass from landfill streams (Fadiel & Abu-Lebdeh, 2021). When used at modest replacement ratios (commonly 5–10% by mass of fine aggregate) WD consistently lowers oven-dry density while producing only modest reductions in 28-day compressive strength, provided mixes are properly designed and cured (Abed et al., 2019; Fadiel & Abu-Lebdeh, 2021). The fine particle size and low bulk unit weight explain both the lightweighting effect and the increased apparent water demand observed in experimental programs (Fadiel & Abu-Lebdeh, 2021). In fresh concrete, WD increases paste demand and reduces slump because its porosity sequesters mix water; this loss of workability is routinely controlled by either pre-saturating the WD to a saturated surface-dry condition or by adding water so that the effective w/c is maintained (Abed et al., 2019). Mechanically, the literature shows a practical performance window: at about 5% replacement strength reductions are often minor (<10%), at ~10% reductions become moderate but usable for many non-structural or semi-structural elements (~10–20%), and beyond ~15% strength penalties become large and limit applications to insulating or very lightweight elements (Fadiel & Abu-Lebdeh, 2021). Additionally, WD concretes commonly display more distributed cracking and improved post-peak energy dissipation a serviceability and safety advantage for certain uses provided adequate curing and compaction are applied (Abed et al., 2019).

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2.4.1 Incorporation as a Partial Fine Aggregate Replacement

The use of waste wood powder (WD) typically sawdust or milling fines as a partial replacement for natural fine aggregate (sand) in concrete is a pragmatic example of waste valorization that simultaneously addresses multi pressing problems, the environmental burden of wood-waste disposal and the escalating ecological cost of sand extraction.

A growing body of experimental work has examined how replacing a fraction of fine aggregate with WD affects fresh and hardened concrete properties. The evidence shows consistent, predictable patterns across multiple studies that Wood Dust (WD) increases water demand and reduces fresh slump due to its porosity and surface area, even modest replacement levels (commonly 5–10% by mass of FA) produce only modest reductions in compressive strength while delivering the tangible benefit of reduced unit weight; and higher replacement levels (>15%) magnify porosity effects and lead to marked strength loss, limiting applications to non-structural or insulating components (Siddique et al., 2020; Cabanillas-Hernández et al., 2024; Turgut, 2007).

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2.4.1.1 Rational mixing (WD) / replacement of fine aggregate

In conventional concrete, fine aggregate (FA) provides bulk, packing, and stiffness to the paste aggregate skeleton. Replacing a portion of FA with WD deliberately reduces the proportion of dense mineral solids and introduces low-density organic inclusions. From engineering standpoint this aims to achieve complementary objectives are :

- ❖ To reduce the material's unit weight to produce lightweight concrete with lower dead loads and improved thermal performance; and
- ❖ Divert wood residues from landfill or open burning into long-lived structural or semi-structural products.

The engineering challenge is to preserve an acceptable balance of strength, durability, and workability while reaping the environmental advantages. The empirical literature defines that balance most clearly in the 5–10% WD replacement window (Siddique et al., 2020; Cabanillas-Hernández et al., 2024).

2.4.1.2 Workability in Wood Dust

The most prominent reason of decreased workability of WD bearing mix is the porous and hygroscopic nature of the material. WD particles contain internal cellulosic porosity, and high specific surface area compared to washed sand. During mixing, these pores tie up mixing water, effectively reducing the amount available to lubricate the aggregate paste system. At identical nominal water-cement ratios, concretes with WD thus have low slump and less flowability (Siddique et al., 2020; Thakur et al., 2023).

Across several studies, slump is reduced in an incrementally linear pattern as the percentage of WD is increased. Siddique et al. (2020) reported slump reductions of the order of 10 to 15% with 5 to 10% WD replacement; Thakur et al. (2023) reported greater slump loss at 15% replacement. These trends are quite consistent with the physical expectations of the results when more and more organic fines are used to coat surfaces and fill inter-particle spaces, and thus require more paste. Here most importantly, reduced slump is not a fatal flaw, it is a controllable design variable. (Siddique et al., 2020; Waqar et al., 2024).

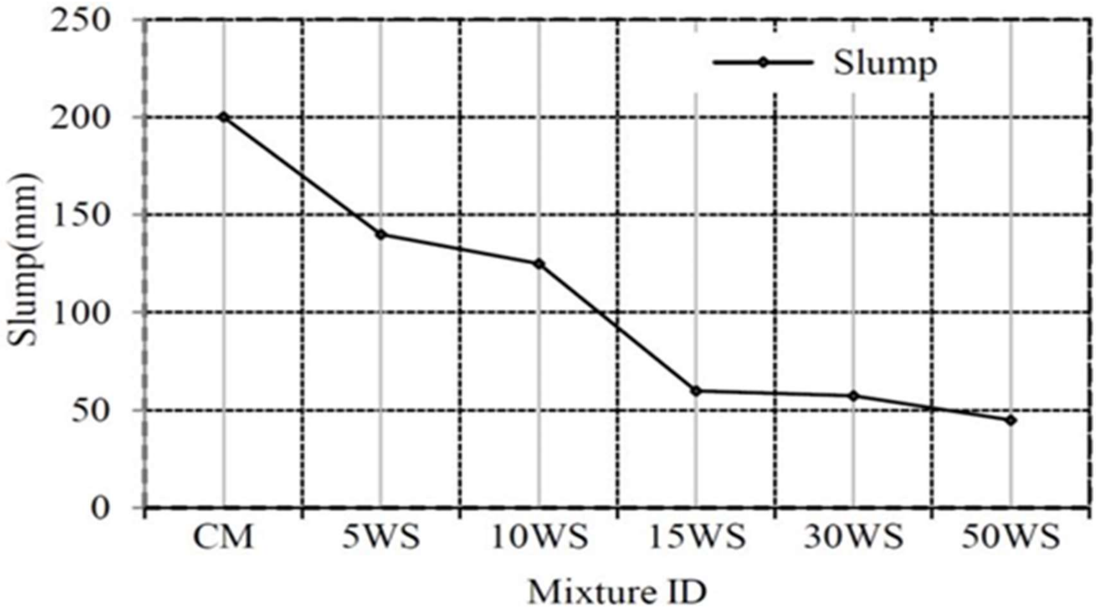

Figure : Slump (mm) vs WS replacement (%) Siddique et al. (2020), Fadiel & Abu-Lebdeh (2021).

2.4.1.3 Compressive strength: dependency on replacement level and curing

Empirical studies uniformly suggest that the substitution of fine aggregate by waste wood powder (WD) affects compressive strength in a dose-response manner and the degree of any reduction is critically dependent on the practices of design mix and curing process. At low levels of substitution (frequently in the region of 5% by mass of fine aggregate), many investigations report low to marginal declines in the value of 28-day compressive strength usually in single digit to low double-digit percentages relative to those of control mixes a result that is frequently found to be acceptable for non-critical structural/semi-structural applications (Siddique et al., 2020).

As replacement increases towards about 10% the reductions become more pronounced (sometimes at the order of 10-20%), indicating a growing contribution of the low stiffness organic inclusions and increasing effective porosity (Dias et al., 2022). When WD content reaches 15% and above the literature shows significant strength penalties commonly above 25-30% for many formulations which generally limit the use of these mixes to lightweight, insulating or non-loadbearing applications (Turgut, 2007).

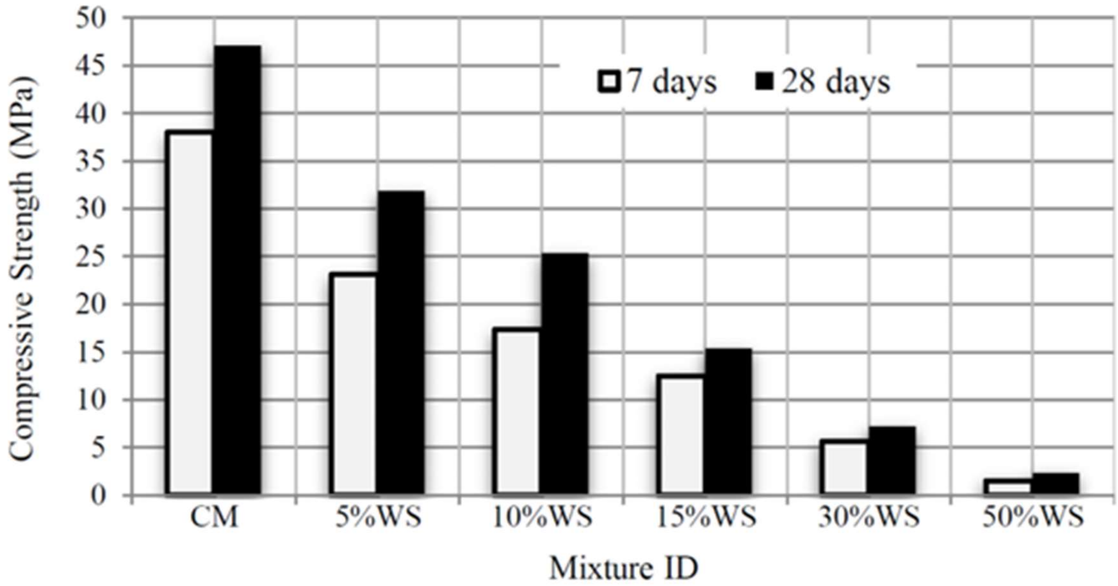

Figure : Compressive strength (MPa) vs WD replacement (%) Siddique et al. (2020), Fadiel & Abu-Lebdeh (2021).

2.4.1.3.1 Primary causes for strength reduction

Strength loss resulting from wood-powder substitution is due to two main, interacting mechanisms. The first is structural dilution: replacement of dense and rigid mineral sand with compliant organic particles which decrease continuity and stiffness of the granular skeleton by which compressive loads are transmitted. Because of the significantly lower elastic modulus and different surface characteristics of the wood particles in comparison with the mineral aggregate, the composite load-bearing capacity per unit volume is decreased with their inclusion. The second mechanism is by pore-structure alteration and the fine porous nature of wood powders increases internal porosity and can unassigned mix water and form an area with higher capillary porosity and possible micro-voids if not adequately saturated or compensated with extra paste (Siddique et. al, 2020; Turgut, 2007).

These processes do not operate independently, the increasing porosity increases the effective loss of structural contact between aggregate and paste, while a poor curing will not allow the internal water of the wood to participate completely in the hydration of the cement. Both effects are therefore sensitive to mix control particularly with water accounting, compaction and curing regime meaning careful the pre-conditioning of WD and optimized curing can materially reduce magnitude strength decline observed at modest replacement levels (Dias et al., 2022).

2.4.1.3.2 Role of curing and internal curing

A critical moderating influence is the quality of curing, and availability of internal curing water. When WD is used in concrete, the water it carries can be slowly released during the hydration period effectively providing an inbuilt cure reservoir and partially neutralizing the strength penalty particularly at early ages. As far as research comparing the strength penalties are lower and similar long-term strength gain can be observed to controls if the replacement is not excessive (Waqar et al., 2024). Therefore, reporting a longer-term (28- and 90-day) strengths is of utmost importance to capture the time-dependent recovery potential.

Research Study	WD replacement (%)	28-day compressive strength (MPa)
Fadiel & Abu-Lebdeh (2021)	0 (Control)	47.1
	5%	31.9
	10%	25.4
	15%	15.4
	30%	7.3

	50%	2.4
Dias et al. (2022) wood chips (WC) series	0 (Control)	64.27 ± 4.00
	5% (WC5)	59.90 ± 3.81
	10% (WC10)	57.67 ± 1.72
	15% (WC15)	51.97 ± 4.12
	20% (WC20)	46.10 ± 1.65
	25% (WC25)	42.83 ± 1.21

Table : 28-day compressive strengths (MPa) for concrete with wood waste (WD) partial fine-aggregate replacement

2.4.1.4 Density (unit weight) and structural consequences

2.4.1.4.1 Quantified benefits

A principal advantage of WD incorporation is the predictable reduction in unit weight. Because WD's measured bulk unit weight is far lower than natural sand, even small replacement fractions yield non-trivial reductions in concrete density. Multiple studies report density reductions in the 6–12% range WD replacement (Cabanillas-Hernández et al., 2024; Hernández-Ocaña et al., 2022). This reclassification toward lightweight concrete is advantageous for reducing structural dead loads and enabling lighter supporting elements.

2.4.1.4.2 Structural and lifecycle consequences

Lower density can translate to practical benefits beyond immediate handling, that may reduce foundation sizes, lower transport emissions per cubic-meter m^3 of installed element, and improved seismic performance due to lower mass. For precast producers, lighter panels enable larger unit sizes for a given handling capacity, and for buildings, reduced dead loads can decrease embodied material in supporting structures, offering indirect carbon and cost savings (Waqar et al., 2024). The engineering objective is to maximize density reduction while keeping strength within target limits. Many literatures show the 5–10% window as the practical compromise appreciable density reduction with limited strength penalty.

2.4.1.5 Ductility and safety performance

Several experimental studies report a shift from brittle to more ductile failure modes with the inclusion of modest WD content. Instead of sudden, localized crushing, WD concretes tend to display more distributed cracking and progressive failure, which offers measurable safety benefits by increasing warning before collapse under extreme loads (Maglad et al., 2023; Cabanillas-Hernández et al., 2024). This ductility enhancement is particularly useful for elements where toughness and post-peak energy dissipation matter.

While current codes do not explicitly address WD-concrete behavior, performance-based design approaches can exploit this property acceptance criteria may combine ultimate strength checks with ductility and toughness metrics, enabling innovative WD-based solutions where appropriate.

2.4.1.6 Design-mix and quality control

The reliable mechanical performance of concretes containing waste wood powder (WD) is not incidental it is the product of deliberate mix design and strict quality control. Across reputable studies, two consistent principles emerge , Firstly WD fractions (commonly 5–10% by mass of fine aggregate) are far likelier to yield acceptable 28-day strengths than larger substitutions and ,Finally the water – cement ratio maintaining for WD added concrete (to control absorbed moisture), and systematic curing regimes materially moderate the strength penalty associated with organic inclusions (Siddique et al., 2020; Dias et al., 2022).

Practically, the WD particle class and its moisture state change the effective water–cement ratio unless accounted for hygroscopic fines sequester mix water at batching and therefore reduce effective paste available for hydration and compaction. Studies that report near-control compressive performance at low WD levels attribute success to either WD pre-saturation or to use of water-reducing admixtures that preserve effective w/c while restoring workability (Siddique et al., 2020). Conversely, experiments that omitted strict moisture accounting or used high replacement (>15%) typically record steep strength declines and high variability (Bourzik et al., 2022; Turgut, 2007).

Quality control extends beyond moisture specifications for WD grading, contamination limits (no paints, oils or deleterious organics), and supplier dry bulk density significantly reduce batch-to-batch scatter. Dias et al. (2022) demonstrate that mixes with carefully characterized wood fractions (volume-based controls, superplasticizer dosing or increasing a w/c around 0.40 ~ 0.6) produced composites that retained serviceable strengths (>25–30 MPa) even with notable wood contents, showing the payoff of tight control and iterative trial mixes. Some researchers who publish both fresh-state metrics (slump, unit weight, air content) and hardened outcomes (28-day strength ± SD, density) provide the most transferable evidence for researchers.

Study (Author, Year)	**WD replacement**	**Mix notes (w/c, admixture, curing)**	**Reported effect on 28-day compressive strength**
Siddique et al., 2020.	5–20% (treated sawdust)	w/c 0.44; water/sodium-silicate treatment of WD; reported use of silica fume in some mixes	**5%** treated WD ≈ control; **10%** often reduced strength (~up to ~30% in some mixes)
Dias et al., 2022.	Up to 15 vol% sawdust; up to 25 vol% wood chips	w/c ≈ 0.40; superplasticizer used; rigorous characterization and curing	Sawdust up to 15 v%: **~0.9–10%** strength reduction; wood chips up to 25 v%: **7–33%** reduction; selected mixes still >25–30 MPa.

Bourzik et al., 2022	Small WWP fractions (1–2.5% in some tests)	mix trials, varied proportions; reported workability and density trends	Workability, density and compressive strength decline progressively with higher WWP; low fractions give manageable reductions.
Turgut, 2007.	Wood sawdust in brick/composite studies (various)	material-specific trials; emphasizes processing and compaction	At higher wood contents (>15%), large strength penalties noted; good processing reduces adverse effects.
Olaiya, 2023 (review).	Review of multiple studies	synthesizes treatment, curing and QA effects	Concludes optimum windows typically fall in 5–10% WD for many mixes; highlights need for standard QC and reporting.

Table: Comparative studies of WD as fine-aggregate replacement.

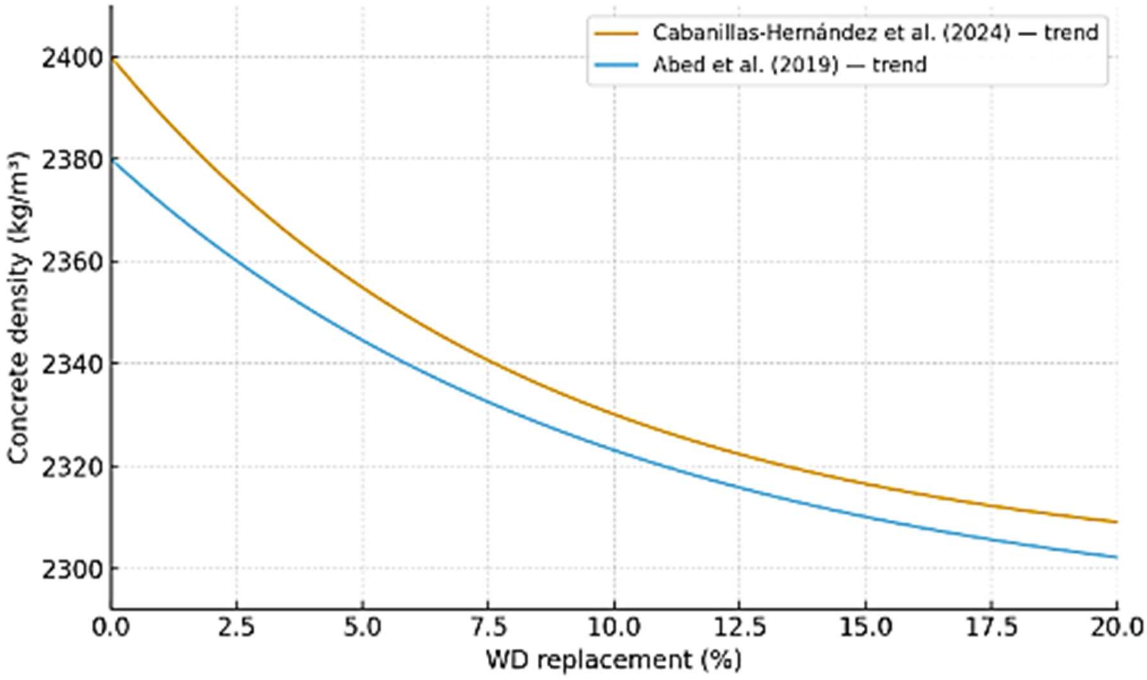

Figure : Concrete density (kg/m³) vs WD replacement (%) Cabanillas-Hernández et al. (2024), Abed et al. (2019).

The literature and the practical relative research experience studies show that waste wood powder is a viable partial replacement for fine aggregate at modest levels (5–10%), delivering meaningful sustainability benefits (reduced sand demand and lower unit weight) with manageable trade-offs in strength and workability (Siddique et al., 2020; Cabanillas-Hernández et al., 2024; Hernández-Ocaña et al., 2022). With appropriate usage of admixture / water-cement control, and curing, WD-bearing concretes can meet serviceability and strength requirements for a wide range of non-critical and semi-structural applications. The experimental matrix, which between 5-12 % of WD mix, is well situated to explore modestly improve mechanical performance and a promising route towards scalable, circular, and low-impact concrete.

2.4.2 Failure and Cracking Patterns

Concrete incorporating waste wood powder (WD) demonstrates distinctive failure and cracking patterns compared with conventional concrete. These behavioral changes arise mainly from differences in density, porosity, and interfacial transition zones (ITZs) between the organic WD particles and the cement paste. While such variations might at first appear to weaken structural performance, a closer review shows that they can provide beneficial features, such as enhanced ductility, delayed crack propagation, and improved post-cracking energy absorption.

The principal, reproducible effects reported across experimental studies are:

- Tendency toward more distributed cracking and increased post-peak energy dissipation,
- Earlier crack initiation at somewhat lower loads where replacement is high, and
- Altered failure surfaces that reflect the compliance and morphology of embedded wood particles.

These altered failure modes are not exclusively negative many studies highlight improved ductility and more gradual post-peak load loss, characteristics that can be advantageous for serviceability and safety in selected applications.

Fadiel & Abu-Lebdeh (2021) present clear photographic evidence and test records documenting how splitting-tensile failure evolves with increasing wood content. In their splitting tests the control mix fractured with a relatively narrow, through-section crack typical of brittle concrete; by contrast the 30% WD mix displayed a wider, more tortuous fracture zone with multiple crack branches, and the 50% WD mix produced an even broader, smeared failure band with evidence of wood fibres bridging crack faces and absorbing energy before separation (Fadiel & Abu-Lebdeh, 2021). The authors interpret these observations as a transition from brittle aggregate-dominated fracture toward a composite mode where organic inclusions interrupt and redistribute stresses, increasing toughness even as peak tensile strength declines.

Different studies report consistent patterns. Dias et al. (2022) observed larger fracture process zones and more distributed cracking in mixes containing sawdust and wood chips, while Maglad et al. (2023) in beam flexure tests with 15% sawdust substitution found reduced stiffness but improved post-peak deformation capacity, with cracks forming earlier yet propagating more slowly under increasing load. Alabduljabbar et al. (2020) and Bourzik et al. (2022) similarly document progressive reductions in peak compressive strength and concomitant increases in visible crack width and damaged zone extent as wood content rises, but they note that failure becomes less sudden and more ductile when the wood fraction is well dispersed and mixes are properly compacted and cured.

Mechanically useful interpretations for practice emerge at modest WD fractions (≈5–10%) the change in failure pattern is modest and often beneficial (slightly more ductile response with small strength trade-offs); at higher fractions (>15–30%) the composite behaviour shifts markedly peak loads fall appreciably and failure is governed by matrix weakness and particle pull-out rather than classic brittle aggregate crushing. These outcomes underscore the need to pair any WD inclusion strategy with stringent mix control and curing procedures so that the desirable toughness gains are realized without unacceptable loss of load-bearing capacity.

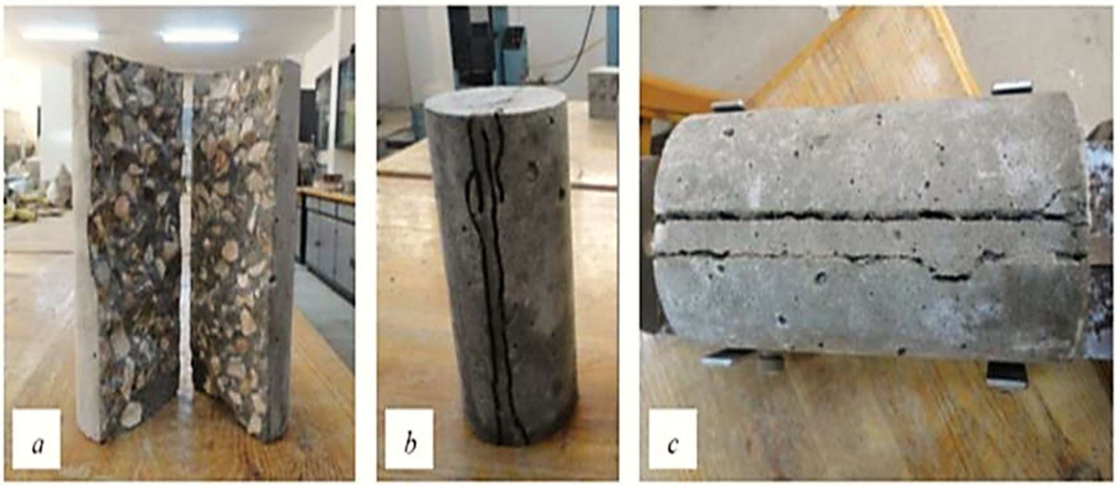

Figure 2.3 : Failure modes of splitting tensile strength for different mixes: (a) Control mix, (b) 30% WD concrete mix and (c) 50% WD concrete mix , Fadiel & Abu-Lebdeh (2021)

2.4.2.1 Failure modes compared to conventional concrete

In normal OPC concretes, failure under compressive load is typically characterized by brittle fracture vertical cracks initiate at mid-height, propagate rapidly, and cause sudden collapse with little warning. Several studies on WD concretes report that failure tends to be less brittle. For instance, Maglad et al. (2023) found that reinforced concrete beams with 5–7% WD showed more gradual load–deflection curves and exhibited ductile flexural cracking rather than sudden shear or compression failure. This is attributed to the lignocellulosic nature of WD, which introduces deformable inclusions within the matrix.

Cabanillas-Hernández et al. (2024) similarly observed that WD concrete cylinders showed wider, more distributed cracks rather than localized fracture planes. The wood particles, being less stiff than mineral sand, act as crack deflectors, redistributing stresses and reducing the risk of explosive spalling. These findings suggest that WD concrete offers a more controlled failure pattern a safety-enhancing trait in service conditions where progressive failure is preferable to brittle collapse.

2.4.2.2 Crack initiation and propagation

Cracks in WD concretes often initiate at the wood–cement interfaces due to the organic particles' lower stiffness and hydrophilicity. However, rather than rapidly propagating, cracks are often arrested or deflected around the WD particles. This produces a tortuous crack path that increases fracture energy. Waqar et al. (2024) reported that in mixes with 10% WD, the increased tortuosity delayed ultimate fracture, resulting in a higher energy absorption index compared to controls. This property is particularly relevant for seismic or impact-prone applications where energy dissipation is valued.

2.4.2.3 Splitting test (tensile) cracking

Split tests on WD concretes support the same behaviour. Hernandez-Ocaña et al. (2022) demonstrated that the crack spacing of 10% WD-beams and prisms was larger but the crack widths were smaller than in reference specimens. This is a stress redistribution and not domination of a few wide cracks, but stress is distributed over multiple smaller cracks. In practical terms, this minimizes the risk of catastrophic fracture and can lead to better performance under non-heavy loads also an increase in serviceability.

2.4.2.4 Practical implications

From a design standpoint, the shift towards more ductile failure modes and increased crack distribution offers advantages in terms of structural safety. Even if WD reduces peak compressive strength, its ability to moderate cracking and provide warning before collapse could make it useful in elements where ductility and toughness are more important than ultimate compressive resistance. For example, non-structural walls, lightweight slabs, or seismic energy-dissipating components may benefit from such behavior.

Summary of failure and cracking trends

- Brittleness decreases with WD; ductile characteristics emerge.
- Cracks are more distributed and tortuous, slowing failure progression.
- Energy absorption capacity increases, particularly at 5–10% WD.
- Safety margins improve due to more gradual failure behavior.

These findings reinforce the role of WD not only as a sustainability measure but also as a performance enhancer in specific contexts where controlled, ductile failure is desirable.

2.4.3 Literature Tables and Graphical Synthesis

To consolidate findings on WD incorporation in concrete, comparative tables and figures are essential. The following tables summarize compressive strength and density behavior trends reported in the literature. Suggested graphs illustrate common patterns-

WD Replacement (%)	General Strength Trend	Key Observations	Source(s)
5%	Slight decrease (<10%)	Minimal effect on compressive strength; viable for structural and non-structural uses	Siddique et al. (2020) ; Maglad et al. (2023)
10%	Moderate decrease (~15–20%)	Lightweight classification achieved; acceptable for non-loadbearing walls and panels	Cabanillas-Hernández et al. (2024) ; Hernández-Ocaña et al. (2022)
15%	Significant decrease (>25%)	Noticeable strength loss; ductile cracking patterns; suitable only for lightweight/partition elements	Turgut (2007) ; Waqar et al. (2024)
20%	Major decrease (>35%)	High porosity; best suited for insulation or acoustic panels	Thakur et al. (2023)

Table : Previous Research on Compressive Strength Trends with WD as Fine Aggregate Replacement

Reference	WD Replacement (%)	Density Observation	Workability Effect
Siddique et al. (2020)	5–10	Density reduced by ~8%; still in normal concrete range	Slump loss ~10–15%
Cabanillas-Hernández et al. (2024)	10	Density reduced 8–12%; lightweight category	Moderate slump reduction
Hernández-Ocaña et al. (2022)	10	Classified as lightweight	Noticeable slump loss, recoverable with admixtures
Maglad et al. (2023)	7	Reduced density, lighter beams	Manageable workability with pre-wetting

Table : Effect of WD on Concrete Density and Workability

The research studies indicate a consistent performance window for WD concretes. At low replacement levels (5–10%), compressive strength and workability remain technically acceptable, with strengths reduced by less than 20% compared to controls (Siddique et al., 2020; Hernández-Ocaña et al., 2022). The lightweight benefit emerges strongly in this range, with density reductions of 6–12%, enough to reclassify mixes as lightweight concretes in some standards (Cabanillas-Hernández et al., 2024).

Beyond 10% replacement, the trade-offs become more pronounced compressive strength drops steeply, and workability becomes more challenging. Yet, even at 15–20% WD, useful properties emerge, such as extremely low density, enhanced ductility, and improved crack distribution (Turgut, 2007; Waqar et al., 2024). These mixes are ideal for insulation blocks, partition walls, and lightweight non-structural elements.

The cracking studies provide a strong argument for ductility as an added-value trait of WD concretes. Instead of sudden brittle collapse, WD concretes show gradual failure, finer cracks, and greater energy dissipation. This aligns with current performance-based engineering goals, where resilience and serviceability under extreme loads are as important as peak strength (Maglad et al., 2023; Waqar et al., 2024).

Overall, WD concretes embody a balanced sustainable solution

- At 5–10% → **eco-friendly, lightweight, and structurally adequate**.
- At 15–20%→ **lightweight, ductile, and resilient**, suited for specialized applications.

This confirms that WD is not simply a waste filler but a functional engineering material with distinct design benefits.

Table : Compressive strength (MPa) vs. WD replacement level (%)From Fadiel & Abu-Lebdeh

Mix ID	WD (%)	7-day (MPa)	28-day (MPa)
CM (Control)	0	38.1	47.1
WD-5	5	23.1	31.9
WD-10	10	17.4	25.4
WD-15	15	12.5	15.4
WD-30	30	5.7	7.3
WD-50	50	1.5	2.4

Table : Concrete density (kg/m³) vs. WD replacement level (%)From Abed et al. (2019, Int. J. Integrated Eng.)

Replacement (%)	Density (kg/m³)
0	2432
10	2300
15	2133
20	2024
25	1837
30	1733

Table : Load–deflection curves (RC beams)From Fadiel & Abu-Lebdeh (2021)

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Mix ID	Wood Dust (WD) (%)	Flexural strength (7d, MPa)	Flexural strength (28d, MPa)
CM	0	4.6	6.3
WD-5	5	3.5	3.6
WD-10	10	3.1	3.4
WD-15	15	2.8	3.1
WD-30	30	1.4	1.8
WD-50	50	3.2	3.5

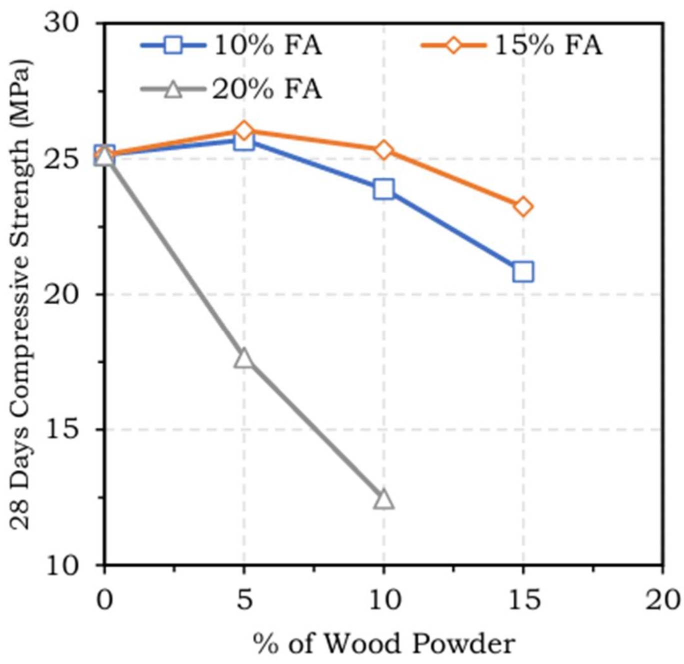

Fig ,: 28 days compressive strength at different % wood powder level (Tarikul Islam et al. 2021)

2.5 Waste Iron Dust (ID) in Concrete

The recovery and reuse of metallic machining residues broadly termed here as waste iron dust (ID) provides a high-value pathway for concrete performance improvement and the diversion of potentially harmful industrial fines to landfill. Iron dust is produced in great quantities in the manufacturing industries during machining, grinding, cutting and polishing Normally, composed of a great deal of iron and iron oxides, these particles are typically very fine, dense and angular. Because of that combination very fine particle size, high particle density, and inert mineral character ID will behave differently in concrete compared with coarser mineral fillers or conventional supplementary cementitious materials. The emerging applied literature reveals that ID, when judiciously applied and at low dosage, has the most useful application confined to micro-filler that improve packing, open porosity refinement, transport pathway refinement and provide practical improvement of compressive and flexural performance and multiple durability indices (Ghannam, Najm & Vasconez, 2016; Largeau, Mutuku & Thuo, 2018; Miah et al., 2020; Ekop et al., 2022).

The mechanisms of ID which contributes to concrete performance, examines empirical outcomes on a number of measures of workability, strength, makes practical recommendations of dosage and processing. The discussion emphasizes on, practical engineering results and provides advice for the practical use of ID for mix designs.

2.5.1 Incorporation as a Micro-filler Additive

Micro-fillers material in binders is primarily a physical strategy to refine particle packing and reduce capillary porosity, while also providing abundant high-surface-area nucleation sites that accelerate early C–S–H formation; finer fractions can additionally interact chemically with aluminate phases under certain blend conditions (Li & Cao, 2024; Cao et al., 2019). The combined filler/packing and nucleation effects typically improve early-age densification and strength when micro-fillers are used at modest dosages, whereas excessive replacement reduces available clinker and hydration products and thereby impairs long-term strength (Zhang et al., 2020; Juhart et al., 2021). The influence on fresh-state rheology is strongly dependent on particle fineness and specific surface very fine micro-fillers increase yield stress and apparent viscosity and therefore raise water demand unless compensated by admixtures or optimized particle grading (Cao et al., 2019; Niewiadomski et al., 2021). From a sustainability and mix-design perspective, the micro-filler/eco-filler approach enables clinker reduction while maintaining target performance, but it requires particle-packing–based proportioning and empirical verification of mechanical and physical metrics for each mix (Juhart et al., 2021; Li & Cao, 2024). Consequently, implementing micro-fillers in structural concretes demands mix-specific optimization of fineness, dose and workability strategy accompanied by standard mechanical and slump tests to ensure the desired balance between early densification and long-term performance (Li & Cao, 2024).

2.5.1.1 Physical character and role of ID in concrete mixes

Defining attribute of industrial iron dust is its fineness. Reported particle distributions place a significant fraction of ID in the sub-micron to low micrometer range, which contrasts strongly with standard sand fines and even with many cement particles (Largeau et al., 2018). The key engineering consequence is filler action of ID particles that occupy the smallest interstitial voids that remain after cement and sand are packed, thereby increasing the effective packing density of the solid phase. When properly dosed, this packing improvement reduces the volume of capillary pores and shortens connectivity of transport pathways without appreciably changing cement chemistry (Largeau et al., 2018; Ghannam et al., 2016).

A second practical attribute is high particle density. While wood or polymeric wastes lower bulk density, iron dust has the opposite effect per unit mass increases it pack mass and, by improving packing and it can raise bulk density and reduce porosity of the hardened matrix. This allow WD designers to use ID to offset porosity introduced by other lightweight or porous inclusions, or to densify ordinary mixes to enhance durability and mechanical performance (Miah et al., 2020).

Iron dust (ID) is typically chemically inert in the short term at common addition rates; it does not usually contribute significant pozzolanic reactivity comparable to silica fume or fly ash. Thus, its benefits are primarily physical packing, micro-filling and the attendant improvements in transport and mechanical metrics (Ghannam et al., 2016; Largeau et al., 2018).

2.5.1.2 Mechanisms of micro-filler action

At the macro-engineering level, the micro-filler function of ID may be understood through a few interrelated processes

1. **Particle packing enhancement :** Adding a fine fraction increases the packing index of the particle assembly. In volumetric terms, sub-micron iron dust particles lodge into the voids between cement particles and the finer fraction of sand, increasing the total solid fraction per unit volume of paste and reducing the volume available for capillary pores. The improved contact between solid surfaces increases the mechanical integrity afforded by the granular skeleton during hardening (Largeau et al., 2018).
2. **Reduction in capillary connectivity:** When capillary pores are smaller and more discontinuous, the bulk transport of fluids (water, chloride ions, carbon dioxide) through the hardened matrix slow WD. The practical durability advantage is a lowered rate of ingress for deleterious agents, and a measurable reduction in sorptivity and water absorption both standard tests for early-age durability (Ghannam et al., 2016; Miah et al., 2020).
3. **Local nucleation support (physical):** Iron dust (ID) is not a reactive pozzolan, its surfaces provide additional loci where hydration products can deposit during early curing. This increases micro-scale cohesion in the near-particle regions, contributing indirectly to higher apparent density and compressive load transfer (Largeau et al., 2018).
4. **Workable cohesion at low dosages:** The fresh state small amounts of fine, angular powder can improve mix cohesiveness by filling fines that would otherwise act as lubrication deficits between coarse grains. However, carefully dosage-dependent excess fine powder increases specific surface and thus water demand.

2.5.1.3 Iron dust (ID) as a micro-filler additive

When added as a micro-filler, iron dust (recycled iron powder, filings or finely milled Fe-based particulates) acts primarily by improving particle packing and providing high-surface nucleation sites within cementitious matrices. The dominant physical mechanisms are a packing/filler effect, whereby ultrafine iron particles occupy interstitial voids and reduce capillary porosity, producing a denser microstructure, and acceleration effect, whereby the large specific surface area of fine iron particles promotes early formation of hydration products (notably C–S–H), accelerating early age strength development. At elevated addition levels the beneficial effects are offset by a dilution penalty the inert or weakly reactive fraction reduces the effective hydraulic binder content and can increase heterogeneity, which may diminish long-term mechanical performance and impair workability if admixture adjustments are not made (Largeau et al., 2018; Jahami, Younes & Khatib, 2023).

Reported optimal use depends on particle size, morphology and intended role. Finely milled iron powders used as cement-scale micro-fillers typically show peak improvements in porosity and early compressive strength at low replacement levels commonly on the order of ~1–3% by mass of cement in laboratory studies while larger proportions rapidly increase plastic viscosity and reverse strength gains (Largeau et al., 2018; Jahami et al., 2023). When recycled iron powder is employed as a partial replacement for fine aggregate (coarser particle fractions), beneficial mechanical and durability outcomes have been documented for higher replacement ratios (reported up to approximately 30% in mortar/concrete trials), albeit with significant changes to rheology and potential impacts on thermal and shrinkage behavior that require verification (Miah et al., 2020; Ghannam, Najm & Vasconez, 2016; Ismail & Al-Hashmi, 2008).

For practical mix design, material characterization and laboratory validation are essential. Prior to adoption, determine the iron dust particle-size distribution, specific surface area, chemical composition and angularity; perform a series of trial mixes beginning at low cement replacement (e.g., 1% → 3% by mass) to evaluate fresh rheology, early (7 d) and standard (28 d) strength, and relevant durability metrics; compensate loss of workability with suitable superplasticizer or packing-based redesign if required; and assess long-term performance under service-relevant exposures. These measures ensure the micro-filler role of iron dust is exploited to improve microstructure and early performance without compromising long-term mechanical or durability objectives (Largeau et al., 2018; Miah et al., 2020; Jahami et al., 2023).

2.5.1.4 Processing and pre-treatment considerations

ID from industrial sources can vary widely in particle size distribution, moisture content, and contamination (oils, cutting fluids, tramp metals). For reliable performance, the material should be screened, dried and, where necessary, washed to remove organic oils that impair bonding and to control water content. Largeau et al. (2018) and Ghannam et al. (2016) emphasize the value of simple mechanical preprocessing (sieving and drying) to standardize feedstock. For small laboratories, oven-drying at moderate temperatures and sieving to remove coarse tramp particles is a practical route. For more industrial settings, dedicated cyclone separation and magnetic separation can improve quality control and provide a stable, reproducible additive stream.

2.5.1.5 Optimal dosing philosophy

Empirical evidence consolidates around a low-dosage optimum for ID studies repeatedly report peak performance gains in compressive and flexural strength, and in reduced sorptivity, at ID additions in the range 1–3% by mass of cement (Largeau et al., 2018; Miah et al., 2020). At these levels, ID fills critical micro voids without appreciably increasing the effective surface area that the binder must wet. Beyond about 5%, workability begins to suffer and rises water demand. The most robust uses for ID initially at 1% and 2% on a mix design, and documenting fresh and hardened metrics, and then expand to 3% where positive trends persist (Ghannam et al., 2016; Miah et al., 2020).

2.5.2 Impact on Properties

This section aggregates and interprets the experimental evidence on how ID influences fresh concrete behavior, mechanical strength, toughness, and durability indices. Where possible, the discussion, observed trends to practical implementations and mix design choices.

2.5.2.1 Workability and fresh state behavior

Multiple controlled experimental studies show that ID's effect on fresh concrete rheology is strongly dependent on dosage. At very low doses (≤2%), ID can modestly improve cohesiveness and reduce segregation in systems prone to bleeding, because the fine particles occupy interstitial spaces that would otherwise promote bleeding and settlement (Ghannam et al., 2016). The result is a more homogenous mix and improved finish ability for cast surfaces.

However, once ID surpasses a threshold (commonly reported around 2–3% depending on particle fineness and base mix water demand), the fine surface area becomes significant enough to absorb mix water and increase effective water demand. Largeau et al. (2018) documented a near-linear slump decline with increasing ID content beyond ~2%, a trend consistent with fundamental rheological behavior of suspensions with rising fine content.

To realize the benefits without incurring adverse workability decline, different research shows how to handle and use it in concrete :

- Use low initial ID dosages **(1–2%)** and measure slump and bleeding;
- Incorporate mid-range water reducers when moving above ~2%;
- Adjust mixing sequence so that ID is dry-blended with cement rather than added late to minimize agglomeration.
- Record slump before and after admixture addition for each ID level; track the air content and fresh unit weight since fine powders can affect entrapped air.

2.5.2.2 Compressive strength trends

Consistent empirical gains at low dosage at different base mixes and aggregates, ID additions in the 1–3% range often produce measurable improvements in 28-day compressive strength. Largeau et al. (2018) reported 12–15% increases at 1–3% ID in some binary blends; Miah et al. (2020) observed optimal gains near 2% in mortar systems; Ghannam et al. (2016) documented an ~8% increase when iron powder partially replaced sand at higher replacement levels in a granite–iron system.

Strength increases occur because the primary physical explanation is pore volume reduction and increased particle contact. With fewer large capillary voids and better particle packing, the load transfer across the hardened matrix is more efficient, leading to higher apparent compressive strength. Because ID does not generally introduce major chemical reactivity at these dosages, the gains are considered structural enhancements via mechanical densification rather than chemical strengthening.

Gains plateau and then decline as fines content groWD. When ID is used beyond ~5–10% (either as replacement of sand or as additive by mass), some adverse effects become prominent increased water demand that, if not compensated with admixtures, reduces effective w/c and can paradoxically lower strength or cause poor compaction and excessive fines can lead to poor compaction and trapped air, negating packing benefits. Empirical studies show that the sweet spot remains at small additions for a net positive outcome (Largeau et al., 2018; Miah et al., 2020).

105 For robust comparisons, compressive strength should be reported with mean and standard deviation for at least three replicates per mix, and statistical testing used to determine significance across ID levels.

S.No.	Mix Designation	Partial Replacement Level	7 Days Compressive strength	28 Days Compressive strength
1	Mix 1	0% Iron Powder	16.71	27.85
2	Mix 2	1% Iron Powder	20.69	33.92
3	Mix 3	2% Iron Powder	19.76	31.37
4	Mix 4	3% Iron Powder	18.75	30.24

Table : Compressive Strength Test Results : Inbanila, T. and Priyadharshini, D. (2019)

2.5.2.3 Flexural and tensile behavior

Although compressive gains are more commonly reported, but flexural and tensile properties also benefit from ID at optimized dosages. Largeau et al. (2018) reported up to ~10% flexural strength improvement at 2% ID, associated with reduced crack initiation and narrower crack widths under bending loads. Similarly, Miah et al. (2020) found reduced crack propagation in mortar prisms with ID inclusion.

2.5.2.3.1 Improvements in flexural resistance and crack control

Narrower cracks and delayed crack initiation are significant for durability smaller crack widths reduce ingress of chlorides and other aggressive species. For elements subject to bending or tensile stresses (thin slabs, beams, façade panels), optimized ID additions can therefore both increase ultimate resistance and improve serviceability.

Flexural tests should include not only peak load but also post-peak behavior (load–deflection curves) and crack-width measurement under service loads to quantify both strength and serviceability improvements.

2.5.2.4 Water absorption, permeability and transport properties of waste iron dust (ID)

Transport properties water absorption, sorptivity/permeability, and ionic diffusion control long-term durability of concrete and therefore are central to any evaluation of a new filler or additive. When waste iron dust (ID) is introduced as a finely graded micro-filler, its dominant effect is physical ID particles occupy the smallest interstices in the paste aggregate system, reducing the volume and continuity of capillary pores and increasing tortuosity of transport pathways. The net engineering outcome is a measurable reduction in liquid uptake and slowed ingress of aggressive species a durability gain that is especially valuable when small quantities of ID (optimally in the 1–3% range by binder or total concrete mass) are used.

2.5.2.4.1 Mechanisms that reduce transport (physical, not chemical)

ID's primary contribution is geometric and hydrodynamic rather than chemical. The very fine fraction of ID fills residual micro-voids left after cement hydration and aggregate packing, which reduces total capillary porosity and breaks long continuous pathways for fluid flow. This "pore-blocking and tortuosity" effect lowers both immediate absorption (mass of water taken up on immersion) and the time-dependent capillary uptake measured by sorptivity tests. Because the effect depends on particle size distribution, dispersion quality, and dosage, small, well-dispersed additions (≈1–3%) reliably improve transport properties, while larger dosages can increase effective surface area and water demand and may undo the benefit unless compensated with admixtures and mix redesign.

2.5.2.4.2 Empirical evidence of absorption and porosity

Study showed that, the linear regression relationships linking porosity and water absorption; Largeau et al., OJCE (2018) report that water absorption increases linearly as porosity increases. From their research results showed that reduced porosity at low ID dosage translated into lower water absorption for those mixes.

The Ghannam et al. study show reduced water uptake in iron-modified mixes the absorption reductions on the order of ~10–15% for mixes where fine metallic powders were used to improve packing, a practical magnitude that aligns with the porosity reductions reported by Largeau et al.

From different research results denote that these empirical findings indicate a reproducible optimum at low ID additions (~1–3%, specific value depends on the particle size and base mix), porosity and absorption fall to a minimum; beyond that optimum the fines content increases water demand and porosity trends can reverse.

Table: Porosity at 28 days vs ID content (Largeau et al., 2018) with interpretation

ID addition (%)	Porosity at 28 d (%)	Δ Porosity vs Control (pp)	Interpretation / Engineering note
0 (Control)	19.94	0.00	Baseline porosity for this binary-blend series.
1.0	18.07	−1.87	Porosity reduced by 1.87 pp vs control indicates improved packing at low ID dose.

2.5	16.12	−3.82	Minimum porosity observed (optimal in this series) corresponds to highest compressive performance in the study.
3.5	19.60	−0.34	Porosity nearly returned to control level (small reduction only) suggests diminishing returns or onset of adverse effects.
5.0	21.51	+1.57	Porosity increased above control excessive fines / water demand likely causing worse microstructure at this dosage.

2.5.2.4.3 Implications for ionic transport and service life

Lower water absorption and reduced sorptivity are reliable proxies for reduced diffusivity of chlorides and other ionic species. Although in some research study performed long-term chloride migration tests, the observed decrease in capillary connectivity strongly implies reduced chloride ingress rate and improved carbonation resistance for low-dose ID mixes (the Largeau and Ghannam datasets both infer improved transport resistance from their measured porosity/absorption results). For reinforced concrete in chloride-exposure classes, even modest reductions in transport coefficients can translate to meaningful extensions of maintenance intervals and service life a key sustainability argument for valorizing ID.

2.5.2.4.4 Testing protocol to quantify the iron dust

To quantify the ID effect reliably, use a consistent, ASTM/NT protocol and report both kinetic and equilibrium metrics

Water absorption (ASTM C642) report oven-dry mass, SSD mass, and percent absorption (mean ± SD). Sorptivity (ASTM C1585) plot cumulative absorption per unit area versus time and report the sorptivity coefficient S for early (0–6 h) and later regimes as appropriate. Permeability (NT BUILD 492 or ASTM C1202) where service-life predictions are required, perform at least one migration or permeability test and interpret alongside sorptivity to avoid misreading pore-solution conductivity effects. Record specimen density and measured porosity so absorption values can be normalized and compared on an equal basis. Sieve Analysis (ASTM C136) report for grading.

2.5.2.4.5 Practical interpretation

1. Report dosage curves include porosity and absorption plotted against ID content (e.g., 0, 1, 2.5, 3.5, 5%) so the optimal minimum is visible (Largeau et al. provide exactly such a curve).
2. Control for workability because fines change water demand, report slump/flow and admixture dosing alongside transport metrics (Ghannam and other uploaded studies show that failing to control effective w/c confounds the observed effect).
3. Complementary durability tests where possible, pair absorption with Rapid Chloride Migration (RCM) or equivalent to provide a direct diffusion coefficient for service-life modelling.

2.5.2.4.6 Synthesis of different research on ID behavior

Research consistently shows that small, well-dispersed additions of waste iron dust (≈1–3%) reduce porosity and water absorption and thus improve basic transport properties of concrete. The observed effect is largest near an empirically determined optimum (Largeau et al. locate that near 2–2.5% in their mixes), and it reverses if ID dosage is pushed too high without mix redesign. For practitioners and researchers, ID thus offers a realistic route to enhance strength & longevity of concrete while valorizing an industrial waste stream provided testing follow standard protocols and fresh-state variability is controlled.

2.5.2.5 Shrinkage and dimensional stability

2.5.2.5.1 Drying shrinkage reduction

Miah et al. (2020) observed lower drying shrinkage in mortars with modest ID content (≈2–3%). The mechanism is likely the reduced capillary water and more uniform pore structure, which sloWD the rate of moisture movement and reduces shrinkage gradients that produce cracking. This makes ID-modified concretes attractive for large slabs and precast elements where shrinkage-induced cracking can compromise long-term performance.

2.5.2.5.2 Creep and long-term deformation

The literature contains fewer systematic studies on creep, but denser matrices with reduced water content typically show lower creep deformation under sustained loads. This suggests ID may also contribute positively to long-term deformation properties, a topic suitable for focused future work.

2.5.2.6 Combined environmental and performance benefit (eco-mechanical balance)

ID provides a unique dual benefit that improves material performance at low dosages while simultaneously valorizing an industrial waste that otherwise requires disposal management. Each ton of iron dust incorporated reduces landfill demand and represents an environmental substitution for extracted materials. Economically, ID can be low-cost relative to virgin fines, particularly where ID is locally available and transport distances are low (Ghannam et al., 2016).

From a life-cycle perspective, small additions that increase durability and reduce maintenance cycles offer net environmental benefit. For example, a modest reduction in sorptivity or chloride ingress can delay repair cycles of reinforced elements and thereby reduce embodied energy and emissions over decades.

2.5.3 Literature Tables and Graphical Synthesis

To summarize and make the evidence easily accessible for comparison and thesis figures, the following tables and figure placeholders are recommended. These synthesize the most load-bearing empirical outcomes from the peer-reviewed literature.

Table: Effect of Iron Dust on Workability and Strength (literature synthesis)

Reference	ID Content (%)	Workability	Compressive Strength Effect (28d)	Flexural Strength Effect
Ghannam et al., 2016. Sustainable Materials & Technologies.	5–15 (partial sand replacement in their study)	Reduced slump at >5%	+8% at 10% replacement (reported)	Minor gain (~5%)
Largeau et al., 2018. Open Journal of Civil Eng.	1–5 (additive basis)	Noticeable slump loss beyond ~2%	+12–15% at 1–3%; decline beyond 5%	Up to +10% at 2%

Miah et al., 2020. Materials.	1–3 (additive)	No major fresh loss at ≤3%	+6% at 2% (mortar tests)	Improved crack resistance

2.5.3.1 Research synthesis and engineering prescription

The literature consistently indicates an optimal low-dosage window of approximately 1–3% ID (by mass of cement or by total binder, depending on reporting conventions in the source). Within this window, ID acts primarily as a beneficial micro-filler, improving packing and reducing transport pathways in the hardened matrix, and delivering modest but consistent gains in compressive and flexural strength and in durability indices. At higher dosages the physical disadvantages (increased water demand, reduced slump, possible compaction difficulties) outweigh benefits unless compensated by admixtures or optimized mix workability strategies.

Practically, ID should not be treated as a bulk substitute for sand in high proportions because its principal advantages derive from micro-scale packing and pore blocking rather than volume replacement. Instead, ID is best handled as a low-rate additive whose dosage is tuned to the host mix and whose quality is controlled through basic preprocessing (drying/sieving/washing) and supplier specification.

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CHAPTER III

METHODOLOGY

3.1 General

This chapter elaborate the experimental methodology used to investigate the physical and mechanical properties of concrete incorporating waste wood powder (WD) and iron dust (ID). The study focuses on replacing fine aggregate with WD and examining the effects of ID as a micro-filler. The goal is to evaluate the sustainability and performance of concrete, with particular attention to the concrete's compressive strength, workability, and environmental impact. The methodology adheres to recognized standards, ensuring reproducibility and reliability of results.

3.1.1 Methodological Rationale

54 Concrete is one of the most widely used materials in construction, but its production, especially cement manufacturing, has a substantial environmental impact. Cement production is responsible for approximately 5–7% of global CO_2 emissions (Mehta & Monteiro, 2014). Additionally, the extraction of natural aggregates contributes to environmental degradation. To address these concerns, using waste materials as partial replacements for conventional concrete components is an effective strategy to reduce the environmental footprint of concrete production (Siddique & Klaus, 2009).

Wood dust (WD) and Iron dust (ID), both by-products of industrial processes, are investigated as sustainable alternatives. WD, sourced from sawmills, is used as a replacement for fine aggregate, while ID, sourced from metal workshops, is added as a micro-filler. The key research question is whether these waste materials can improve the sustainability of concrete without sacrificing its mechanical properties. The experiment is designed to assess whether incorporating these materials can enhance the concrete's workability and compressive strength, while reducing its environmental impact.

The procedure followed in this study adheres to recognized industry standards, such as ASTM and ACI guidelines, to ensure the results can be reliably reproduced. These tests include workability, density, compressive strength, and absorption. The research also seeks to demonstrate how waste materials can be integrated into concrete to enhance its sustainability, reduce waste, and improve the overall environmental footprint of construction materials .

3.1.2 Tests Performed

120 The tests performed in this study were:

- 55 **Workability (Slump Test, ASTM C143):** To assess the ease with which the concrete can be mixed, placed, and compacted.
- 21 **Compressive Strength (ASTM C39):** To determine the ability of the concrete to withstand axial loads.
- 113 **Splitting Tensile Strength (ASTM C496):** To measure the tensile strength of the concrete, indicating its resistance to cracking under tension.

These tests were selected to provide comprehensive information about the behavior of the concrete under different conditions, helping to assess the impact of WD and ID on its mechanical performance.

3.2 Research Framework

3.2.1Experimental Design

The experimental design follow WD a factorial approach, focusing on two independent variables Wood Dust (WD) and Iron Dust (ID). These two materials were tested at different levels to assess their effects on concrete's properties. The following levels were used for each material:

- **WD Replacement Levels:** 0%, 5%, 10%, 15%, and a special mix with 7%.
- **ID Addition Levels:** 0%, 1%, 2%, 3%, and a special mix with 10%.

8 This factorial approach allow WD for the assessment of both the individual and combined effects of WD and ID on concrete performance, providing insight into the optimal mix for achieving sustainable concrete with acceptable mechanical properties. The goal is to explore whether these materials can replace conventional concrete components without compromising the concrete's quality.

Fig. : Concrete specimens

86 A total of 84 concrete specimens (100 x 200 mm cylinders) were cast, representing 14 different experimental conditions. Each mix was replicated three times, resulting in 6 specimens per condition, ensuring statistical reliability and providing robust data for analysis. Each specimen was subjected to a series of tests, including compressive strength, splitting tensile strength and workability. This replication strategy ensures that the results are not affected by random variations and provides confidence in the findings.

3.2.2 Research Flowchart

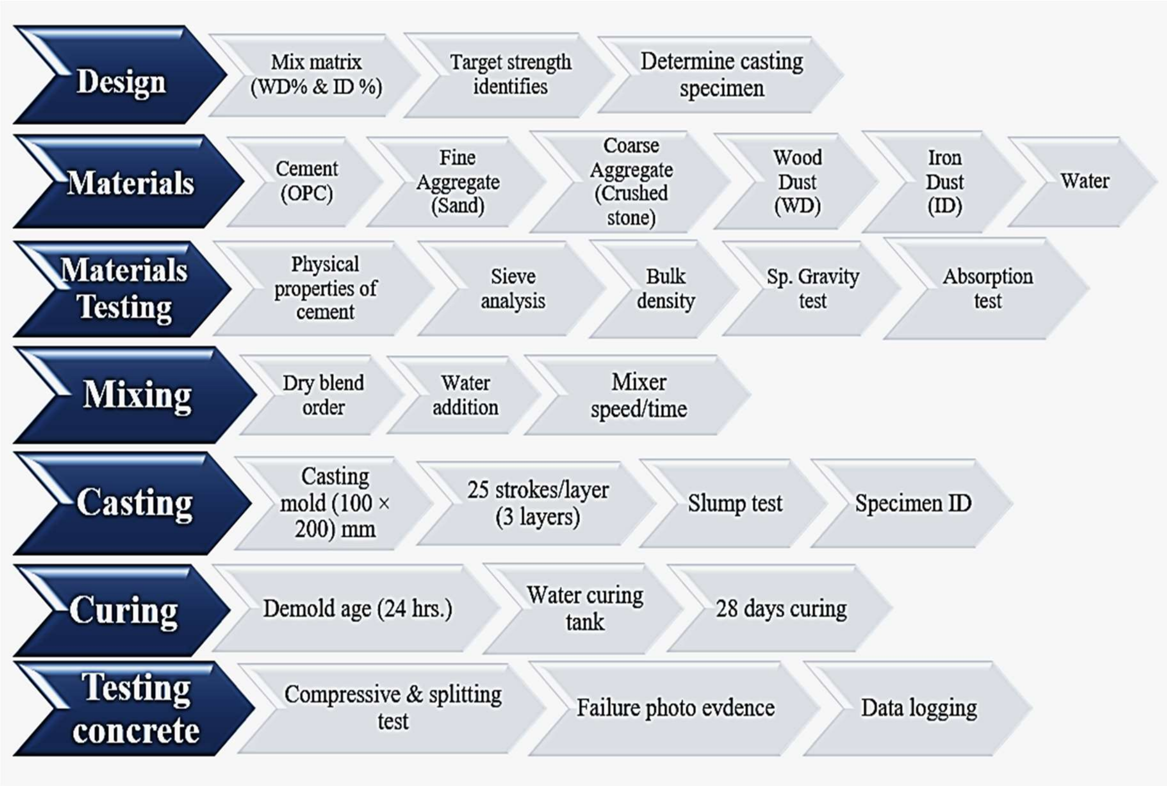

Fig , : Flowchart of Experimental Sequence from Design to Testing.

Each stage of the experimental process is essential for ensuring the quality and consistency of the concrete, from preparing the materials to testing the finished specimens.

3.3 Material Properties of Concrete

3.3.1 Binders (OPC Shah Cement)

The primary binder used in this study was Ordinary Portland Cement (OPC) sourced from Shah Cement, which conforms to ASTM C150 standards for Type I Portland cement. The cement's chemical composition was verified using an SGS certificate, confirming that it met the required specifications for general-purpose concrete (SGS, 2024).

SGS Certificate for Shah Cement

The chemical composition is as follow :

Component	Value (%)
CaO	63.1
SiO_2	20.5
Al_2O_3	5.5
Fe_2O_3	3.2
MgO	2.1
SO_3	3.3
Na_2O	0.4

This composition ensures the cement is suitable for producing durable in concrete mixes (ASTM, 2022).

3.3.2 Aggregates

The aggregates used in this study were Sylhet sand for fine aggregate and crushed stone for coarse aggregate. Both were selected based on their suitability for providing the necessary workability, strength in the concrete mixes. These aggregates were tested in accordance with ASTM C33 (ASTM, 2022), which specifies the standard requirements for aggregates used in concrete production.

3.3.2.1 Properties of Fine Aggregate

In this study Sylhet sand is taken as the fine aggregate. Fine aggregate plays a critical role in determining the workability, strength, and durability of concrete, as it fills the voids between coarse aggregate particles and contributes to the overall particle packing density of the mix. The properties of the fine aggregate used in this research are presented in Table**,** and the particle size distribution (PSD) is shown in Figure **.**

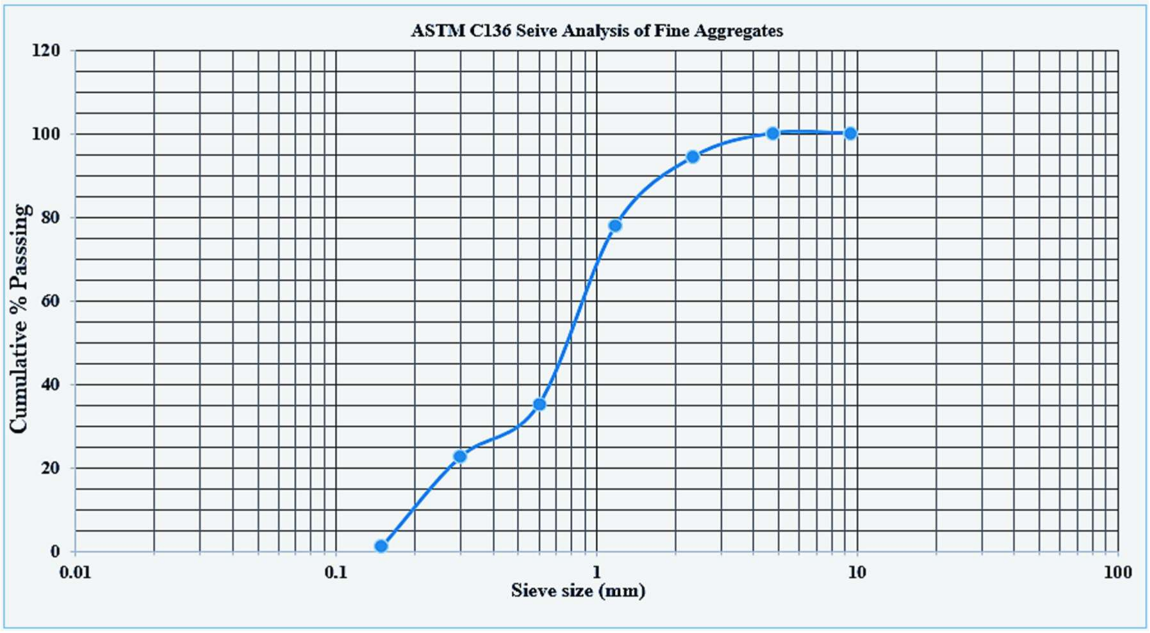

Fig. : Gradation Curve of Fine Aggregate

Property	Value
Fineness Modulus (FM)	2.52
Specific Gravity	2.65
Absorption	1.2%
Bulk Unit Weight (kg/m³)	1,560

Table : Properties of Fine Aggregate

The gradation of the fine aggregate was determined through sieve analysis, conducted according to ASTM C136 (ASTM, 2014). In this method, a known mass of sand was passed through a series of sieves with progressively smaller openings, allowing the determination of particle size distribution. Proper gradation is essential as it affects concrete cohesiveness, minimizes segregation, and influences water demand.

The fineness modulus (FM) of the sand is 2.52, which indicates a medium grading and falls within the acceptable range specified by ASTM C33 (ASTM, 2018). This value ensures a well-graded material, providing a good balance between workability and strength development.

The specific gravity of the fine aggregate is 2.65, a value consistent with natural siliceous sand. This property, measured following ASTM C128 (ASTM, 2015), reflects the relative density of the material compared to water. A higher specific gravity typically indicates denser and stronger aggregate, contributing positively to the mechanical properties of concrete.

The absorption capacity of the sand is 1.2%, which is within the normal range for fine aggregates. Absorption was determined according to ASTM C128, and this moderate value suggests that the aggregate does not excessively draw water from the cement paste. As a result, the effective water–cement ratio remains stable, reducing the risk of inconsistencies in workability and strength.

The bulk unit weight of the sand is 1,560 kg/m³, which aligns with typical values for natural sand and was measured following ASTM C29 (ASTM, 2009). Bulk density influences volumetric batching calculations and indicates the compactness of aggregate particles, which directly affects void content and concrete density.

Collectively, these properties confirm that the fine aggregate used in this study satisfies the requirements of ASTM C33 for concrete applications, ensuring that it is suitable for producing concrete mixes with predictable fresh and hardened properties.

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3.3.2.2 Properties of Coarse Aggregate (Crushed Stone)

In this study, crushed stone is used as the coarse aggregate. The maximum nominal size of the coarse aggregate is 20 mm, with the material retained on a No. 4 sieve. Coarse aggregate constitutes the largest portion of the concrete mix and plays a significant role in defining the strength, stiffness, and durability of the hardened concrete. The properties of the coarse aggregate used in this research are presented in Table , and the particle size distribution (PSD) is illustrated in Figure .

Property	Value
Fineness Modulus (FM)	7.24
Specific Gravity	2.68
Absorption	0.9%
Bulk Unit Weight (kg/m³)	1,440

Table: Properties of coarse aggregate

The grading of the crushed stone was determined through sieve analysis in accordance with ASTM C136 (ASTM, 2014). A representative sample was passed through a series of standard sieves, and the cumulative percentage retained was recorded to develop the gradation curve. Well-graded coarse aggregates improve the packing density of the mix, reduce voids, and minimize cement paste demand, ultimately enhancing both workability and long-term strength.

The fineness modulus (FM) of the coarse aggregate is 7.00, indicating that the material falls within the expected range for crushed stone aggregates and meets the acceptance criteria specified in ASTM C33 (ASTM, 2018). A higher FM reflects the predominance of larger particles, which contribute to reduced shrinkage and creep in hardened concrete.

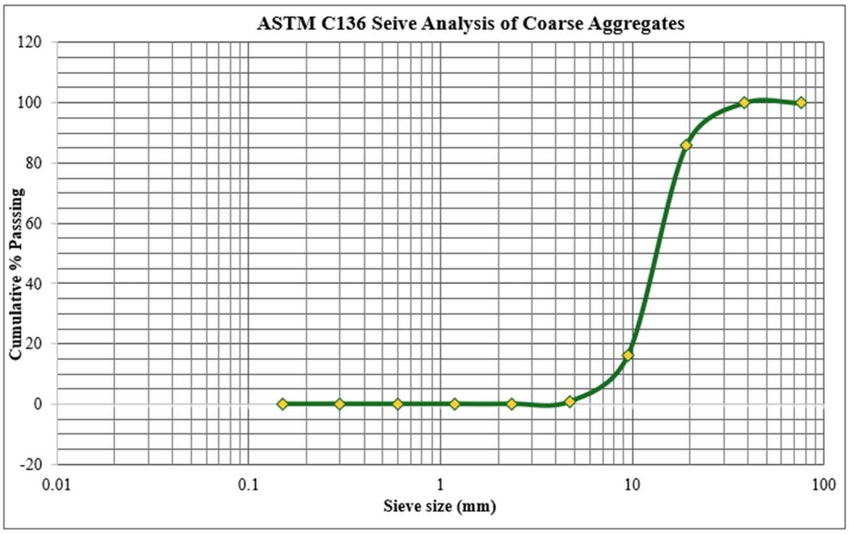

Fig. : Gradation Curve of Coarse Aggregate

The specific gravity, measured in accordance with ASTM C127 (ASTM, 2015), reflects the density of the aggregate relative to water. A higher specific gravity indicates denser and potentially stronger material, which directly contributes to the compressive strength and unit weight of concrete.

The absorption capacity of the coarse aggregate, determined following ASTM C127, represents the water retained within the aggregate pores after immersion. Low absorption values are preferable, as they reduce variability in the effective water–cement ratio.

The bulk unit weight of the coarse aggregate, measured according to ASTM C29 (ASTM, 2009), provides insights into the compactness of the material when placed in a container. This value is essential for volumetric proportioning of the concrete mix and for estimating the percentage of voids between particles.

Overall, the properties of the coarse aggregate used in this research conform to the requirements of ASTM C33 for normal-weight aggregates, ensuring that it is suitable for producing structural concrete with reliable performance in both fresh and hardened states.

3.3.2.3 Selection Rationale

Both the fine and coarse aggregates used in this study were chosen based on their compliance with the relevant ASTM standards, ensuring that they would contribute to concrete with desirable workability and strength. The materials were carefully tested and selected to ensure that the final concrete mix would meet the required specifications for structural use.

3.3.3 Wood Dust (WD)

Wood Dust was sourced from a local sawmill and was used to replace a portion of the fine aggregate. Wood dust (WD) used in this study was collected from various sawmill & furniture shops , at Uttara Azampur and Dhakshin Khan areas as shown in Figure

Fig. : Wood dust (WD) which is used in this study

The collected Wood dust (WD) was sieved to remove other dust practical before we use it .

Fig. : Separating Wood dust (WD)

Wood dust is used as a replacement material for fine aggregate. Wood dust is incorporated into the concrete mix as an alternative to traditional fine aggregates, offering potential benefits in terms of sustainability and material efficiency.

The properties of the wood dust used in this study are provided. The Fineness Modulus (FM) of the wood dust is 2.27, which is typical for fine aggregates. This indicates that the particle size distribution of the wood dust is suitable for replacing fine aggregate, contributing to the workability and stability of the concrete mix. A finer distribution is essential to ensure adequate packing and minimize the risk of voids in the concrete matrix.

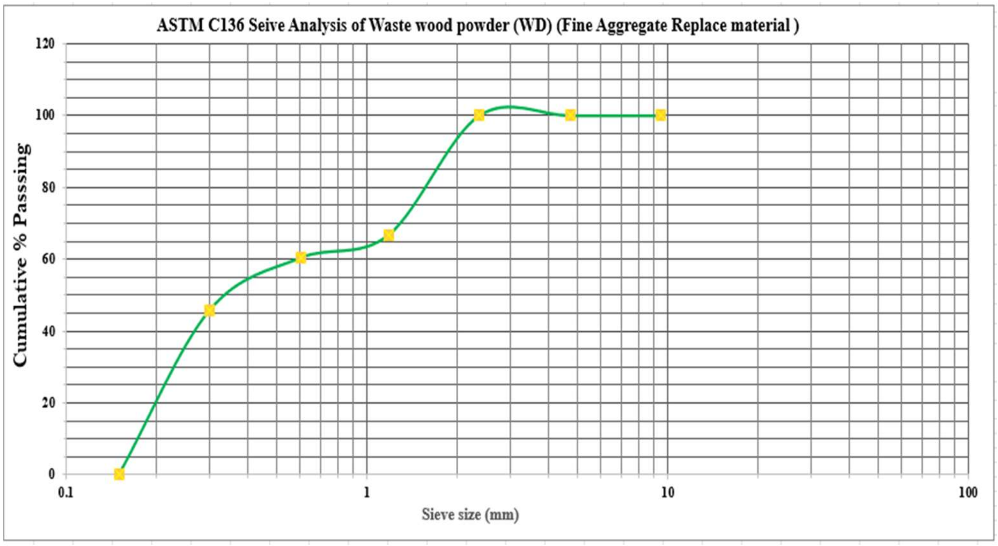

Fig. : Gradation Curve of Wood dust (WD)

The bulk unit weight of the wood dust is 266.43 kg/m³, which is relatively low compared to conventional fine aggregates. This lower unit weight could affect the overall density and weight of the concrete mix .

Fig. : Specific gravity test of Wood dust (WD)

Property	Value
Fineness Modulus (FM)	2.27
Bulk Unit Weight (kg/m³)	266.43

3.3.4 Iron Dust (ID)

Iron Dust was sourced from a local metal workshop as showed in figure . Iron dust (ID) used in this study was collected from various local metal workshop in Uttara Azampur,Dhaka and from comilla as showed in figure

Fig. : Iron dust (ID) which is used in this study

Before using it in concrete mix, all the impurities / external materials (e.g, Rusty nails , Chunks of iron blocks) are removed properly .

Fig. : After Removing Impurities from Iron Dust

In this study, iron dust (ID) was evaluated as a fine material for use in concrete mixes. Iron dust wasn't used for any replacement material , it filler to explore its effects on mix design and material performance. The measured physical properties of the iron dust are given below and used to guide mix adjustments.

The fineness modulus (FM) of the iron dust is 0.8, indicating a very fine, powder-like particle-size distribution. This low FM means the material has a high surface area and can improve particle packing when used in small amounts. However, higher surface area usually increases water demand and can reduce workability unless additional mixing water are used.

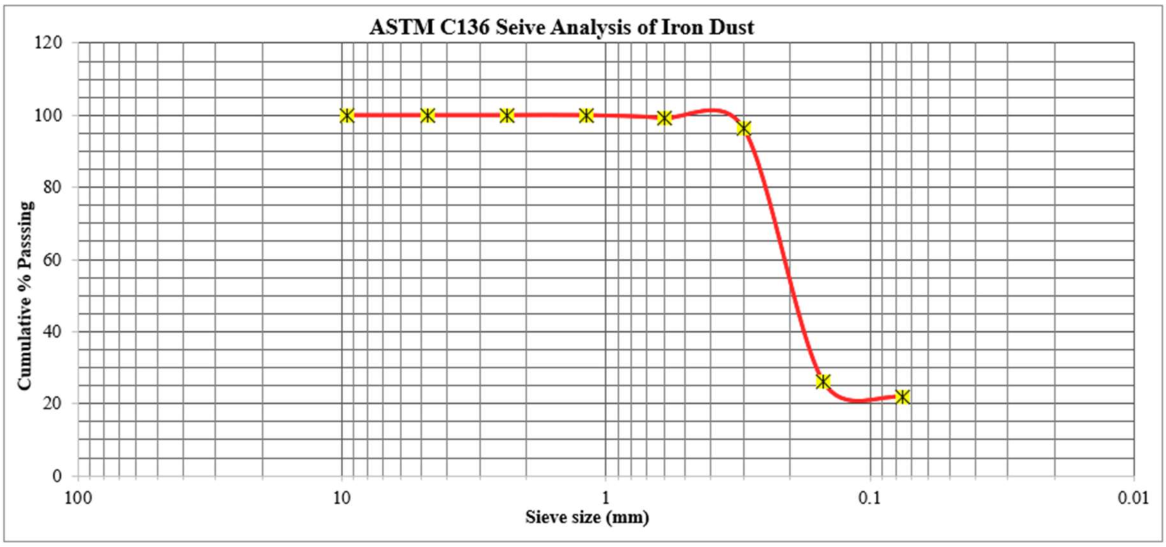

Fig. : Gradation Curve of Iron Dust (ID)

The bulk unit weight of the iron dust is 1908.51 kg/m³, which is much higher than that of conventional fine aggregates. Incorporating ID will increase the bulk density of the concrete and may raise the dead load. In some cases, higher density can contribute to improved compressive strength, but actual effects depend on replacement level and interaction with the cement matrix.

The observed particle class is fine powder. As a powder, iron dust can act as a filler to reduce voids and refine the concrete microstructure, potentially decreasing porosity. At the same time, its powder behavior may alter rheology, increase the risk of segregation, and require careful control during mixing and compaction. If the iron dust is an industrial by-product, it should be tested for contaminants (e.g., oils, heavy metals) and for corrosion risk, since metallic iron can oxidize and affect durability.

Property	Value
Fineness Modulus (FM)	0.8
Bulk Unit Weight (kg/m³)	1908.51
Observed Particle Class	Fine powder

Different research studies clam that addition of ID enhances the packing density of the mix, improving compressive strength and reducing porosity.

3.3.5 Water

Water used for mixing was potable tap water, complying with ASTM C94 requirements. The water-to-cement ratio was consistently maintained at 0.60 across all mixes (ASTM, 2022).

3.4 Design Mixing Proportion of Concrete

3.4.1 Control Mix

The control mix serves as the baseline for this study and was designed to achieve a target compressive strength of approximately 20 MPa at 28 days. This strength is typical for medium-strength concrete used in various structural applications. The control mix followed a standard concrete mix ratio of 1 : 2.31 : 3.02 for cement, fine aggregate, and coarse aggregate, respectively, and a water-to-cement ratio (w/c) is 0.60. This w/c ratio is provided for adequate hydration while maintaining workability and strength .

For the control mix, the batch masses per cubic meter of concrete were calculated as follow :

Material	Mass (kg/m³)
Cement	341.67
Fine Aggregate	789.28

Coarse Aggregate	1030.29
Water	202.66

The selection of natural sand as the fine aggregate and crushed stone as the coarse aggregate was based on their consistent properties and suitability for standard concrete. The specific gravity and absorption rates of the aggregates met the standards outlined in ASTM C33 (ASTM, 2022).

3.4.2 Wood Dust (WD) Replacement Levels

Wood dust (WD) was used as a partial replacement for fine aggregate in the experimental mixes. The use of WD is a sustainable approach to reduce waste in construction materials and has been shown to improve concrete's sustainability. The replacement levels of WD were set at 5%, 10%, 15%, and a special mix with 7% WD to evaluate the impact of varying levels of replacement on concrete properties. Previous studies have shown that replacing fine aggregate with WD does not significantly compromise compressive strength if the replacement level is kept within reasonable limits (Aparna et al., 2018).

The following batch proportions were used for the different WD replacement levels per cubic meter :

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Mix Percentage	Cement (kg)	Fine Aggregate (kg)	WD (kg)	Coarse Aggregate (kg)	Water (kg)
WD (5%)	341.67	749.82	39.46	1030.29	202.66
WD (10%)	341.67	710.35	78.928	1030.29	202.66
WD (15%)	341.67	670.89	118.392	1030.29	202.66
WD (7%)	341.67	734.03	55.25	1030.29	202.66

3.4.3 ID Addition Levels

Iron dust (ID) was used as a micro-filler in this study. ID is a by-product of metal machining and is often used in concrete mixes for its ability to enhance packing density, improve strength, and reduce porosity. The ID was added at 1%, 2%, and 3% by mass of cement, and a special mix with 10% ID was tested to examine the maximum potential of ID as a filler material. The fine particle size and low absorption rate of ID make it suitable for use in concrete mixes to improve their mechanical properties, particularly in terms of compressive strength .

The following batch proportions were used for the different ID addition levels:

Mix	Cement (kg)	Fine Aggregate (kg)	WD (kg)	ID (kg)	Coarse Aggregate (kg)	Water (kg)
M5	341.67	749.82	39.46	23.89	1030.29	202.66
M6	341.67	710.35	78.928	23.89	1030.29	202.66
M7	341.67	670.89	118.392	23.89	1030.29	202.66
M8	341.67	749.82	39.46	47.78	1030.29	202.66
M9	341.67	710.35	78.928	47.78	1030.29	202.66
M10	341.67	670.89	118.392	47.78	1030.29	202.66
M11	341.67	749.82	39.46	71.68	1030.29	202.66
M12	341.67	710.35	78.928	71.68	1030.29	202.66
M13	341.67	670.89	118.392	71.68	1030.29	202.66
M14	341.67	734.03	55.25	238.924	1030.29	202.66

3.4.4 Special Mix (7% WD + 10% ID)

The special mix was created by combining 7% WD and 10% ID to explore the potential synergistic effects of using both materials in concrete. Previous studies suggest that the combination of WD and ID could provide optimal performance by improving both the mechanical properties and workability of the concrete. This special mix was selected to test whether combining these two waste materials could result in a concrete mix that not only performs well in terms of compressive strength but also maintains ease of handling and placement.

The batch proportions for the special mix were as follow :

Mix ID	Cement (kg)	Fine Aggregate (kg)	WD (kg)	ID (kg)	Coarse Aggregate (kg)	Water (kg)
M14	341.67	818	62	38	1030.29	202.66

The special mix provides an opportunity to evaluate how both materials interact to produce a concrete with superior mechanical properties, making it a critical component of the research.

3.5 Sample Preparation and Casting

3.5.1 Mixing Procedure

The preparation of concrete specimens followed standardized procedures to ensure consistency, reproducibility, and adherence to the specified mix designs. The mixing process involved the careful selection of materials, precise weighing, and controlled mixing to ensure the correct proportions of cement, aggregates, WD, ID, and water. Mixing was carried out in a mechanical concrete mixer following ASTM C192/C192M-19 (ASTM, 2022), which provides guidelines for making and curing concrete test specimens in the laboratory.

Fig , : Concrete Casting Step by Step following ASTM C192/C192M-19 (ASTM, 2022)

1. **Weighing and Preparation of Materials**: The required amounts of each material were carefully weighed before mixing. The cement used in this study was 341.67 kg/m³, fine aggregate was 789.28 kg/m³, coarse aggregate (crushed stone) was 1030.29 kg/m³, and water was 202.66 kg/m³. These values were based on the mix design calculations for the control mix, ensuring that the water-to-cement ratio (w/c) was maintained at 0.60.Dry Mixing: The dry ingredients (cement, fine aggregate, coarse aggregate, WD, and ID) were placed into a mechanical concrete mixer. The dry materials were mixed for 1-2 minutes to ensure that they were thoroughly blended, allowing the WD and ID to disperse evenly throughout the mixture.

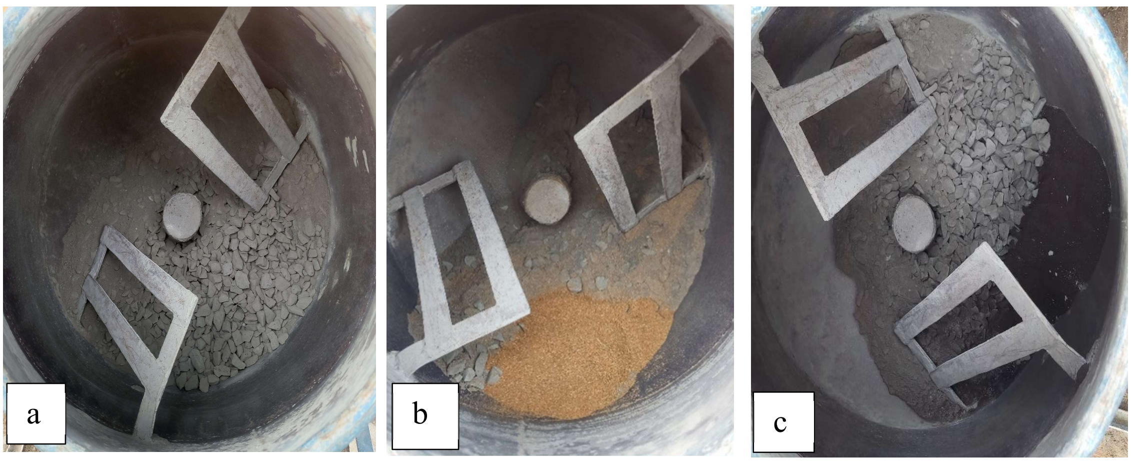

Fig. : Different dry mix : a) Control (PC) , b)Replacing fine aggregate by wood dust (WD) 5% added in concrete; & c) Adding iron dust 3% in concrete with 5% replacement of fine aggregate by wood dust (WD).

2. **Adding Water:** The required amount of water was added to the dry mix gradually to achieve the desired consistency. The water-to-cement ratio was kept constant at 0.60 for all mixes, which is a typical ratio for concrete that achieves a good balance between workability and strength (Bentz et al., 2008). The water was mixed for an additional 3- 4 minutes to ensure thorough hydration of the cement.

Fig. : In dry mix after adding water in concrete.

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3. **Mixing Time:** After adding the water, the mix was thoroughly blended for an additional 3 – 4 minutes to achieve a homogeneous consistency. This step ensured that all the materials, including WD and ID, were properly hydrated and that the mix had an even distribution of particles.

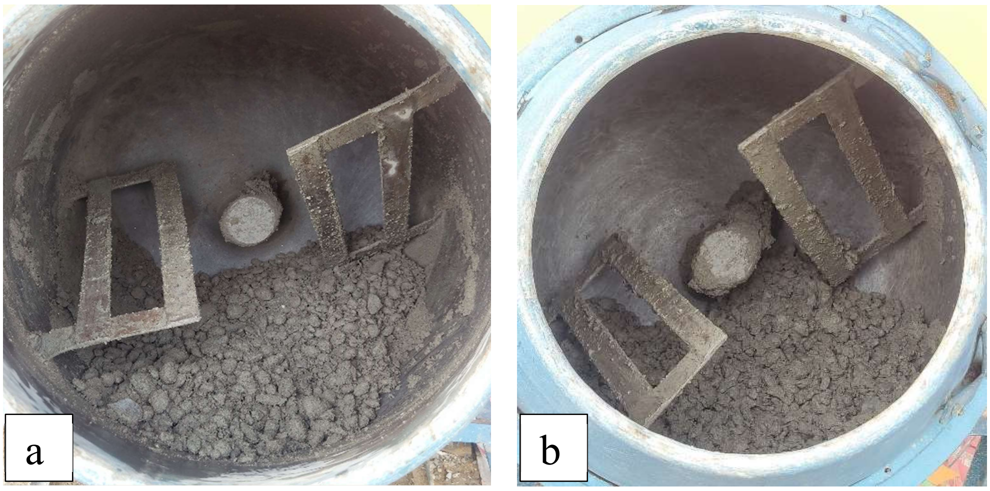

Fig. : After adding water to different mixes . a)15% Wood dust (WD) and 3% Iron dust (ID) added ; b) 5% Wood dust (WD) & 3% Iron dust (ID) .

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4. **Workability Check (Slump Test):** After the mixing process, the workability of the concrete was checked using the slump test (ASTM C143, ASTM, 2022). The slump test measures the flowability and consistency of the mix. When the slump was too low, indicating low workability, additional water was added in small increments.

Fig. : Slum test Performed

3.5.2 Workability Adjustments

Workability is a critical factor when incorporating alternative materials such as WD and ID. Both materials can affect the consistency and flow of the concrete. Therefore, the following adjustments were made to ensure that the concrete maintained optimal workability:

1. **Effect of Wood Dust (WD):** As wood dust tends to absorb moisture affect the water-to-cement ratio of the mix, as WD can absorb excess water (Siddique & Klaus, 2009).
2. **Effect of Iron Dust (ID):** Iron dust, being a fine powder, increased the viscosity of the mix, which does not much impact (in lower percentage) on workability. ID particles tend to fill the voids in the aggregate matrix, leading to increased packing density. This improves compressive strength but can improve workability (in higher percentage). Thus, constant monitoring of the slump was essential to ensure the mix remained workable without compromising its density.

Fig. : Workability Test (Slump Test).

3.5.3 Molding & Compaction

Molding and compaction were carried out according to ASTM C31 (ASTM, 2022), which provides guidelines for preparing and curing concrete specimens. The following procedures were followed:

1. **Filling the Molds:** The prepared concrete was poured into standard 100 x 200 mm cylindrical molds. Concrete was poured in three equal layers, ensuring that each layer was properly compacted to remove any air voids. This is essential for achieving high strength and durability in the final concrete specimens.

2. **Compaction Method:** The concrete was compacted using the rodding method (ASTM C31, ASTM, 2022). A steel rod with a diameter of 16 mm was used to tamp each layer of concrete. During compaction 3 layer are divided for each specimen for each layer 25 strokes were applied to ensure proper consolidation. This method ensures that all air pockets are removed, and the mix is fully compacted to avoid voids that could negatively affect the strength.

3. **Surface Leveling:** After compaction, the surface of the concrete was leveled using a trowel to ensure that it was flush with the top of the mold. This step is important for ensuring uniform dimensions and proper curing.

4. **Mold Removal:** After the concrete had been compacted and leveled, the molds were covered with plastic to retain moisture and left to set for 24 hours. After this initial curing, the specimens were demolded carefully to prevent damage and placed in a curing tank for 28 days at a controlled temperature of 28°C.

3.5.4 Demolding & Identification

After curing for 28 days, the specimens were carefully demolded and identified as per the following procedure:

1. **Demolding**: The molds were removed after 24 hours of initial setting, following ASTM C31 guidelines (ASTM, 2022). Special care was taken during the demolding process to avoid damaging the specimens.

2. **Identification**: Each specimen was marked with a unique identification number corresponding to the specific mix used (e.g.,M1,M2,M3……...M14). This identification system was crucial for tracking and correlating each specimen to its respective test data.

3. **Curing Conditions**: Once demolded, the specimens were placed back in a water curing tank for the remainder of the curing period. The curing tank was maintained at a constant 28°C to ensure proper hydration and strength development. The curing

conditions were monitored regularly to ensure that the specimens remained in a consistent environment until testing (Neville, 2012).

Fig. : Demolded Concrete Specimens with Identification Mix ID and Date of Casting.

3.6 Curing Regime

The curing of concrete is essential for ensuring adequate hydration and strength development. All specimens were cured according to ASTM C31 guidelines (ASTM, 2022). The key factors in curing included temperature control and moisture retention, which were closely monitored throughout the curing process.

- **Curing Duration**: All specimens were cured for 28 days in a water curing tank. This period allows WD for the cement to fully hydrate and the concrete to achieve its target strength. The temperature of the curing tank was maintained at a constant 28°C, which is typical for standard curing conditions (Bentz et al., 2008).

- **Water Curing**: The water curing method was chosen to maintain consistent moisture content in the concrete and to prevent premature drying, which could hinder the hydration process. The water level in the curing tank was regularly checked and replenished to ensure that the specimens remained immerged during the entire curing period.

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- **Post-Curing Storage**: After the 28-day curing period, the specimens were removed from the curing tank and allowed to air-dry before testing. This step was crucial for preventing any distortion or cracking that could arise from moisture evaporation.

Fig , : Post-curing specimen

3.7 Testing Methods

134 The testing methods for this study were carried out according to recognized ASTM standards to ensure the accuracy, reliability, and reproducibility of results.

3.7.1 Workability (Slump, ASTM C143)

4 The workability of the concrete mixes was evaluated using the slump test, which measures the consistency and flowability of the concrete. The procedure followed ASTM C143 (ASTM, 2022) and involved filling a slump cone with fresh concrete, lifting the cone, and measuring the height difference of the concrete after the cone was removed. 32 The slump was measured in millimeters, with the ideal slump range for most concrete mixes falling between 75 and 100 mm.

Fig.: Workability Test (Slump Test)

3.7.2 Density & Unit Weight (ASTM C138)

The density of the concrete specimens was measured to determine the unit weight of the concrete. This measurement was essential for assessing the compactness of the mix and for calculating the total weight per unit volume. The unit weight was determined by measuring the mass and dimensions of each cylindrical specimen and applying the formula:

$$Unit\ Weight = \frac{Mass}{Volume}$$

3.7.3 Compressive Strength (ASTM C39)

Compressive strength tests were conducted in accordance with ASTM C39 (ASTM, 2022). The concrete cylinders were tested at 28 days using a Universal Testing Machine (UTM). The specimens were placed in the machine and subjected to a load at a constant rate of 0.25 MPa/s until failure. The maximum load at failure was recorded and used to calculate the compressive strength.

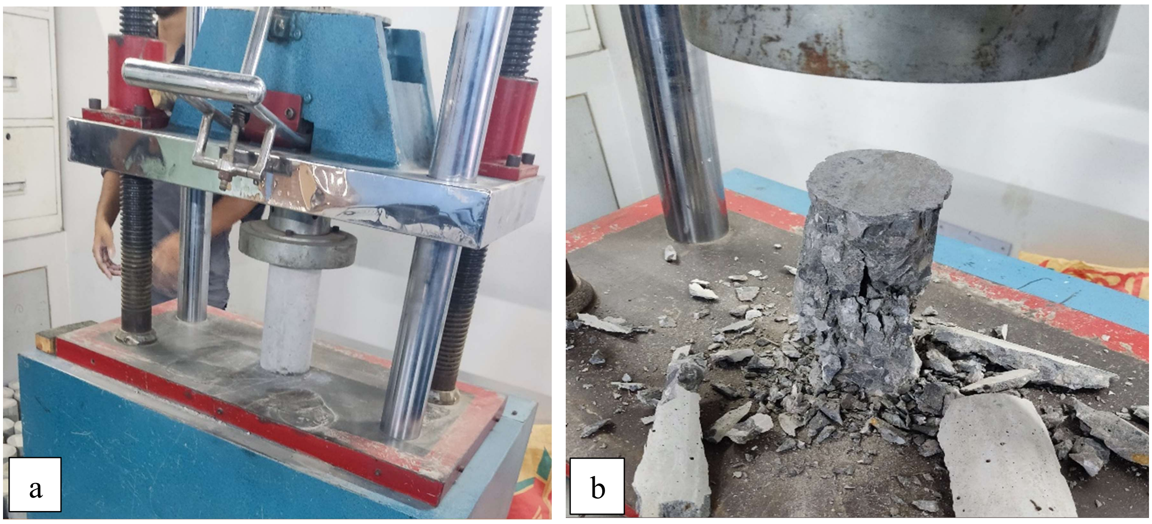
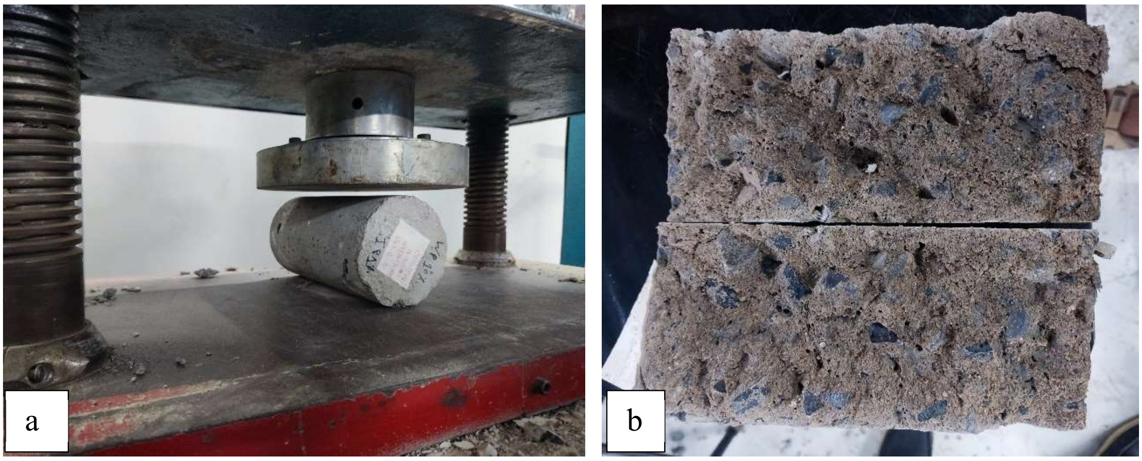


Fig : Compressive Strength Test Performed by (Universal Testing meshing , UTM) (ASTM C39) . a)Before applying load ,b)After applying load.

3.7.4 Splitting Tensile Strength (ASTM C496)

The splitting tensile strength was determined using the **ASTM C496** method (ASTM, 2022). This test measures the tensile strength of concrete by applying a compressive load to a concrete cylinder placed horizontally under the test machine. The cylinder is loaded until it splits, record the value to calculate the splitting tensile strength:



Fig, : Splitting Tensile Strength Test Performed by (Universal Testing meshing , UTM) (ASTM C496) a)Before applying load ,b)After applying load.

3.7.5 Failure / Crack Pattern Documentation

Failure patterns and cracks were documented through visual inspection and photography. This included classifying failure types (e.g., brittle, ductile) and measuring crack widths where applicable. Representative photographs were taken to document the failure modes of concrete with different WD and ID combinations.

Fig , : Different Failure / Crack Pattern . a) M1 at Compressive strength tests, b)M1 at Splitting Tensile Strength test ,c)M11 at Compressive strength tests, d)M14 at Compressive strength tests, e)M4 at Splitting Tensile Strength test, f) M13 at Splitting Tensile Strength test.

3.8 Experimental Matrix

The experimental matrix was developed to map each mix ID to its corresponding batch proportions and testing conditions. The matrix ensures that all data can be traced back to the specific mix it corresponds to. It also lists the number of replicates for each test condition and identifies control and experimental groups.

Mix ID	WD (%)	ID (%)	Target Strength (MPa)	Number of Specimens
M1	0	0	20	6
M2	5	0	20	6
M3	10	0	20	6
M4	15	0	20	6
M5	5	1	20	6
M6	10	1	20	6
M7	15	1	20	6
M8	5	2	20	6
M9	10	2	20	6
M10	15	2	20	6
M11	5	3	20	6
M12	10	3	20	6
M13	15	3	20	6
M14	7	10	20	6

3.9 Unit Weight of Concrete

The unit weight of the concrete was determined by measuring the mass and dimensions of the cylindrical specimens

Mix	Mass (*kg*)	Diameter (*mm*)	Height (*mm*)	Volume (m^3)	Unit weight (kg/m^3)
M1	3.727	99.827	200.328	0.001568	2377
M2	3.546	99.638	201.389	0.00157	2258.2
M3	3.225	99.282	201.872	0.001563	2063.6
M4	2.984	100.237	200.389	0.001581	1887
M5	3.59	99.867	201.583	0.001579	2273.6
M6	3.366	99.602	201.478	0.00157	2144.2
M7	3.299	99.822	200.889	0.001572	2098.4
M8	3.62	100.18	200.722	0.001582	2288
M9	3.351	99.403	201.556	0.001564	2142.3
M10	3.438	100.748	202.894	0.001617	2125.6
M11	3.536	99.217	199.306	0.001541	2294.7
M12	3.363	100.797	200.033	0.001596	2106.9
M13	3.539	100.155	203.278	0.001601	2209.8
M14	3.731	100.194	200.122	0.001578	2364.6

The unit weight of the concrete mixes was recorded, and the results were plotted to show the effects of varying WD and ID levels on the overall density of the concrete.

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CHAPTER IV

RESULTS AND DISCUSSION

4.1 Introduction

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This chapter presents the measured fresh and hardened performance of concrete mixtures in which waste wood powder (WD) partially replaced fine aggregate and waste iron dust (ID) was used as a micro-filler additive. The experimental indicators reported here are: fresh workability (slump), 28-day compressive strength and 28-day splitting (indirect tensile) strength. All tests were executed using standard test methods (ASTM C143 for slump, ASTM C39 for compressive strength, ASTM C496 for splitting tensile), and results shown below are the averages reported in the laboratory.

The structure of the section follows WD a logical path first fresh behaviour (workability), then compressive strength, then splitting tensile behaviour and failure patterns, followed by a synthesis focused on the combined (WD + ID) mixes and practical implications for application and mix control.

4.2 Fresh behaviour - Slump (workability)

4.2.1 Measured slump values (summary)

The control mix (PC) recorded a slump of **115 mm** (reference fresh mix). Slump values for the WD and WD+ID mixes are reproduced on the table. The test results of different specimen value with the variation percentage of slump value are plotted at the table below

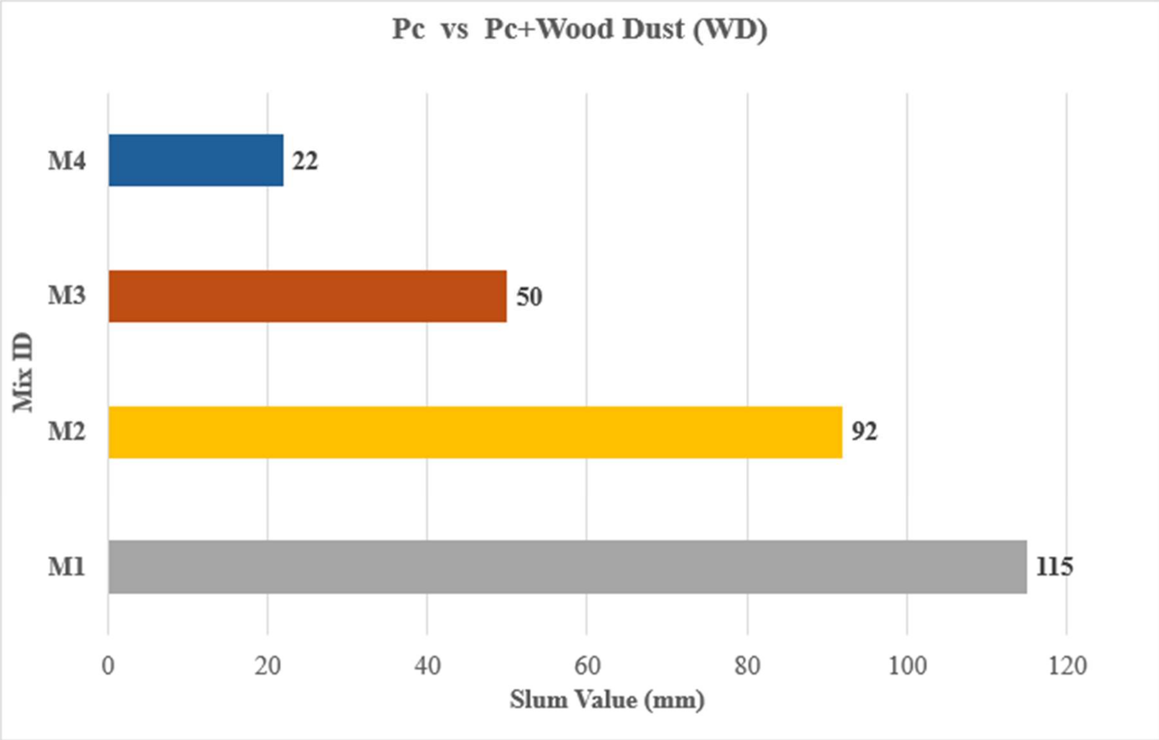
Specimen	Slump (mm)	Variation (%)	Increase / Decrease
M1	115	—	—
M2	92	−20.00%	Decreased
M3	50	−56.52%	Decreased
M4	22	−80.87%	Decreased
M5	93	−19.13%	Decreased
M6	52	−54.78%	Decreased
M7	20	−82.61%	Decreased
M8	85	−26.09%	Decreased
M9	48	−58.26%	Decreased
M10	18	−84.35%	Decreased
M11	85	−26.09%	Decreased
M12	50	−56.52%	Decreased
M13	20	−82.61%	Decreased
M14	75	−34.78%	Decreased

Table : Specimen slump values with variation percentage.

4.2.2 Interpretation

Two clear trends emerge:

1. Increasing WD content substantially reduces slump value. The addition of waste wood dust (WD) markedly reduces concrete workability. Using M1 (115 mm) as the reference, slump dropped to 92 mm (M2), a reduction of 20.0%, then to 50 mm (M3), −56.5%, and to 22 mm (M4), −80.9%.



Fig, : Comparison between plain concrete vs wood powder combined concrete.

2. Comparable reductions appear across the other mix groups (M5–M8, M9–M12, M13–M14), indicating a consistent trend that, increasing WD content leads to lower slump. This behaviour is consistent with the porous, water-absorptive nature of wood particles .

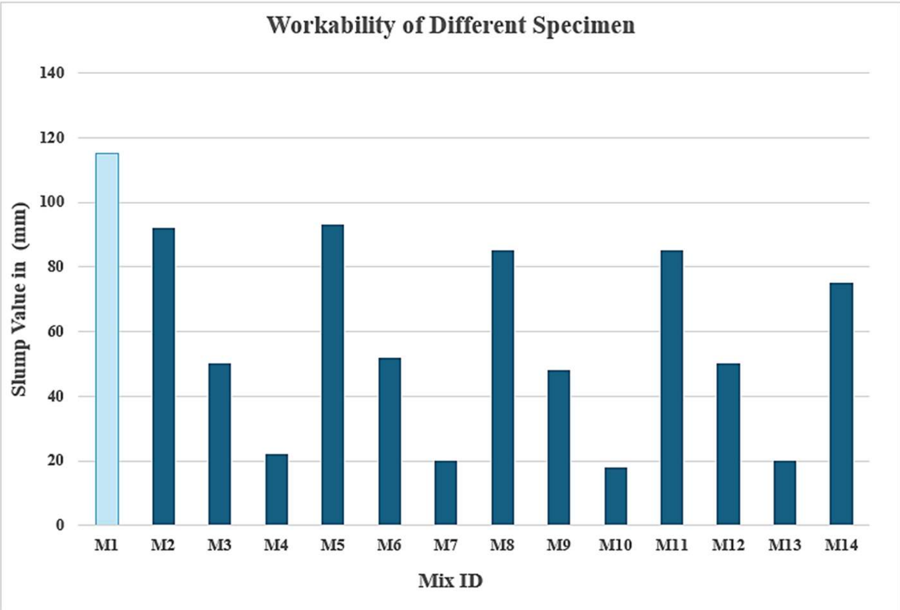


Fig ,: Workability of Different Specimen.

3. ID has a small but detectable influence for the same WD level, ID at 1–3% produced modest changes in slump (± a few mm). At low ID dosages the effect is near-neutral sometimes a small reduction which is consistent with past studies that report fine metallic powders raise surface area but also can improve packing and cohesiveness (Miah et al., 2020; Largeau et al., 2018).

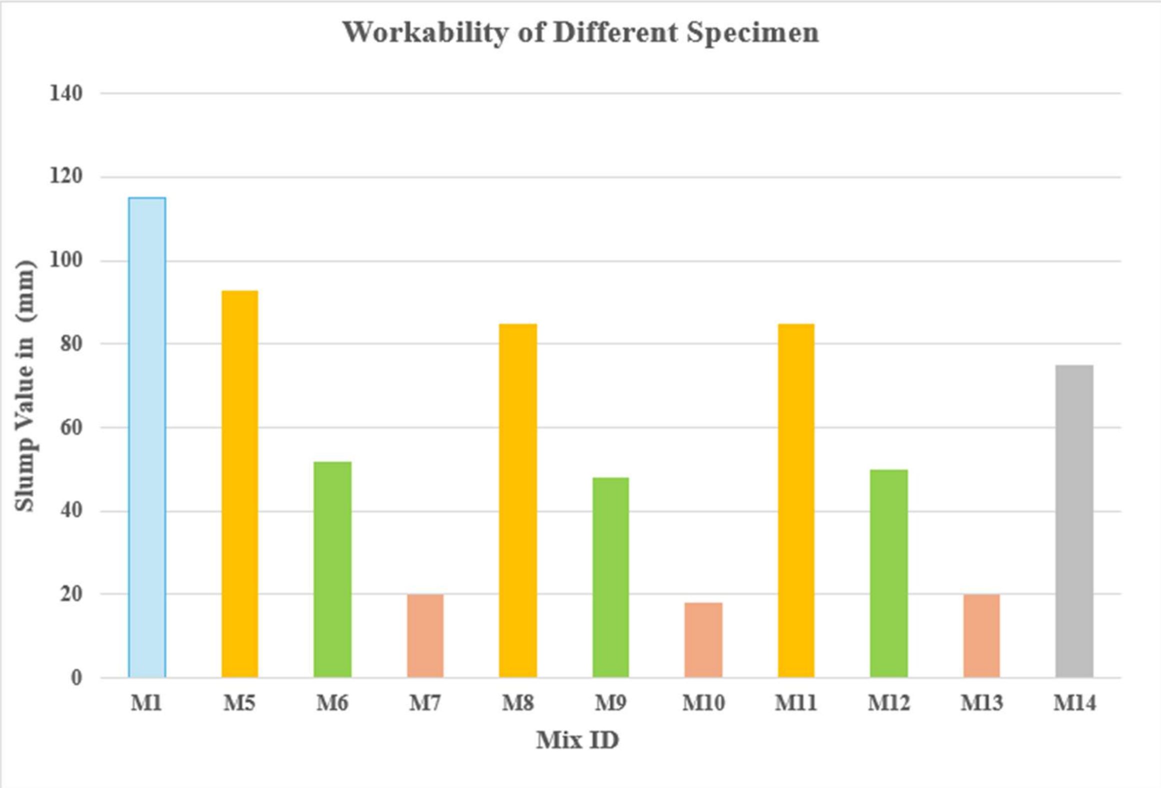
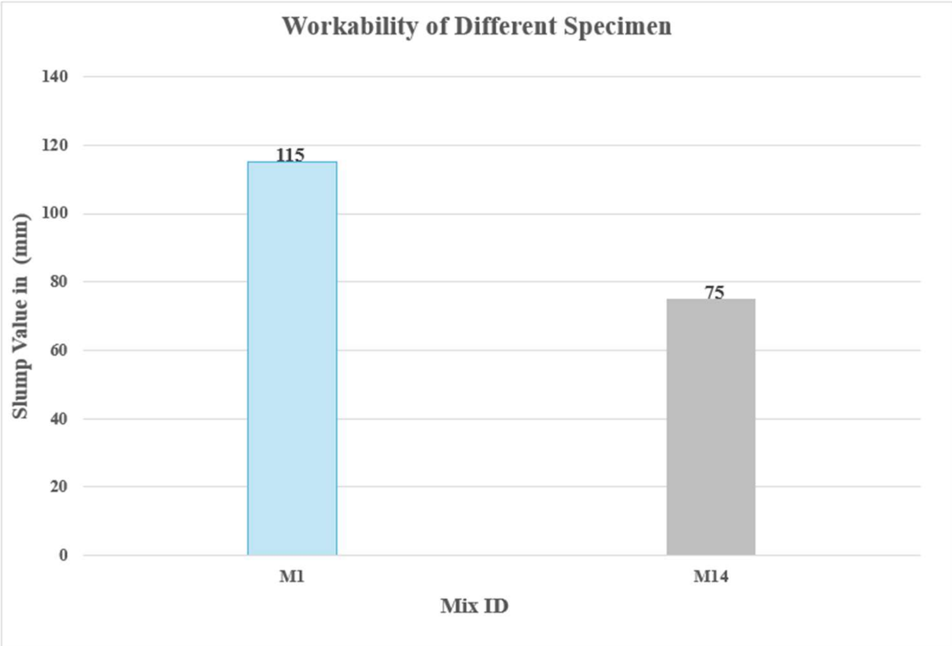


Fig ,: Comparison between plain concrete vs wood powder and iron dust combined concrete.

4. The special mix (M14) had a slump of 75 mm, which lies between the low-WD and moderate WD values and indicates the combined formulation is workable though reduced vs control.



Fig, : Comparison between M1 vs M14

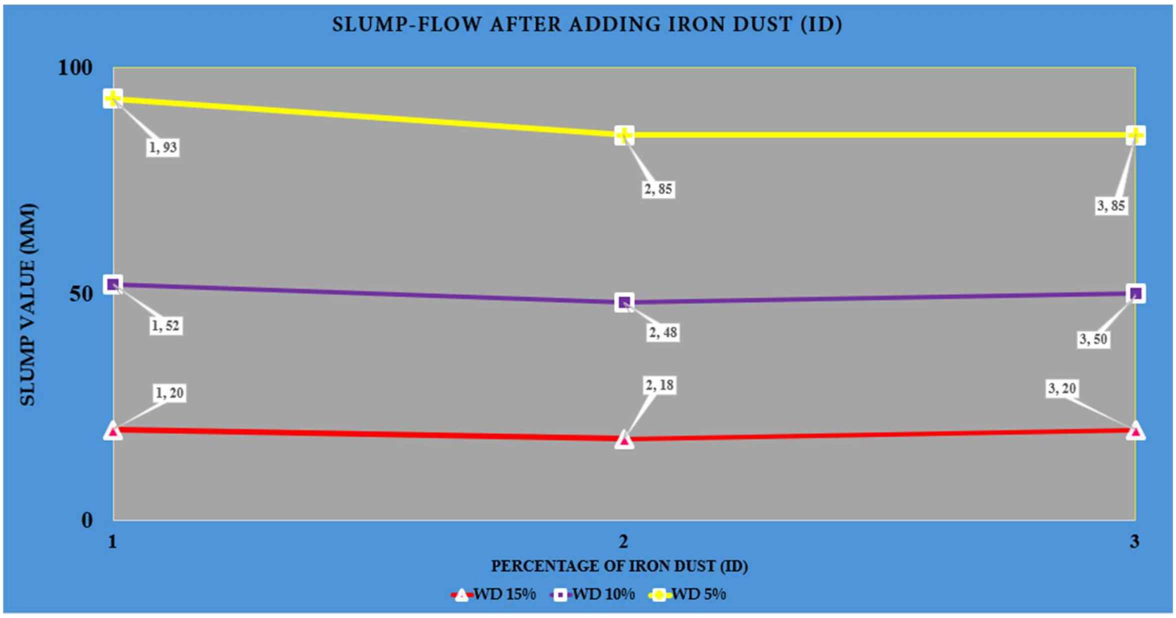
The recorded slump reductions indicate the need for strict batching control (ASTM C143) and controlled use of water-cement ratio if a target slump is required in production. This directly follow WD common practice in waste-aggregate concretes (ACI 211.1 guidance on proportioning and handling additives).

4.2.3 Slump flow after addition iron dust (ID) in different percentage of wood dust (WD)

The slump-flow data indicate a consistent, dose-dependent effect of iron dust (ID) on the fresh rheology of WD-containing concretes. For all three wood-replacement levels (5%, 10% and 15%), the measured slump values decline slightly from ID = 1% to ID = 2% and then show a small recovery or plateau between ID = 2% and ID = 3%. In other words, the immediate impact of added ID is a modest loss of free flow as ID increases to 2%, after which further ID causes little additional slump reduction and, in some mixes, produces a slight rebound in measured flow.

Two complementary mechanisms explain this behaviour. First, the very fine ID particles increase the overall specific surface area of the solid fraction and thus raise the mixture's water demand, causing an initial slump reduction (higher yield stress / apparent viscosity) as ID increases (Cao et al., 2019; Niewiadomski et al., 2021).

Second, at modest dosages (≈1–3%) the iron fines act as an effective micro-filler and packing agent: they fill micro-voids between cement and fine aggregate and improve internal cohesion, which can reduce segregation and help sustain flow in cohesive mixes this explains the observed stabilization or slight recovery in slump between 2% and 3% ID (Largeau et al., 2018; Miah et al., 2020). The net result is a shallow U/flattening response rather than a continuous linear decline.



Fig, : Slump-flow after adding iron dust (ID) in wood dust (WD)

The graph shows that iron dust can be used to fine-tune workability of WD concretes, low dosages give improved homogeneity and cohesiveness with only modest loss of mobility; dosages above the effective packing window risk higher water demand and placement difficulties unless admixture compensation or SSD preconditioning of WD is applied. For the mixes tested here the working window around ~1–2% ID appears to balance cohesion and flow best, but this should be confirmed statistically for each material source.

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4.3 Effect of WD & ID on Compressive Strength of Concrete

In Fig. it can be observed that the 28-day compressive strength of concrete decreases as the percentage of waste wood dust (WD) used to replace fine aggregate increases. Addition of iron dust (ID) to WD-containing mixes partially mitigates the strength loss, and the magnitude of recovery depends strongly on the ID dosage and the WD level. The numerical results for the tested mixes are summarized in Table and plotted in Fig.

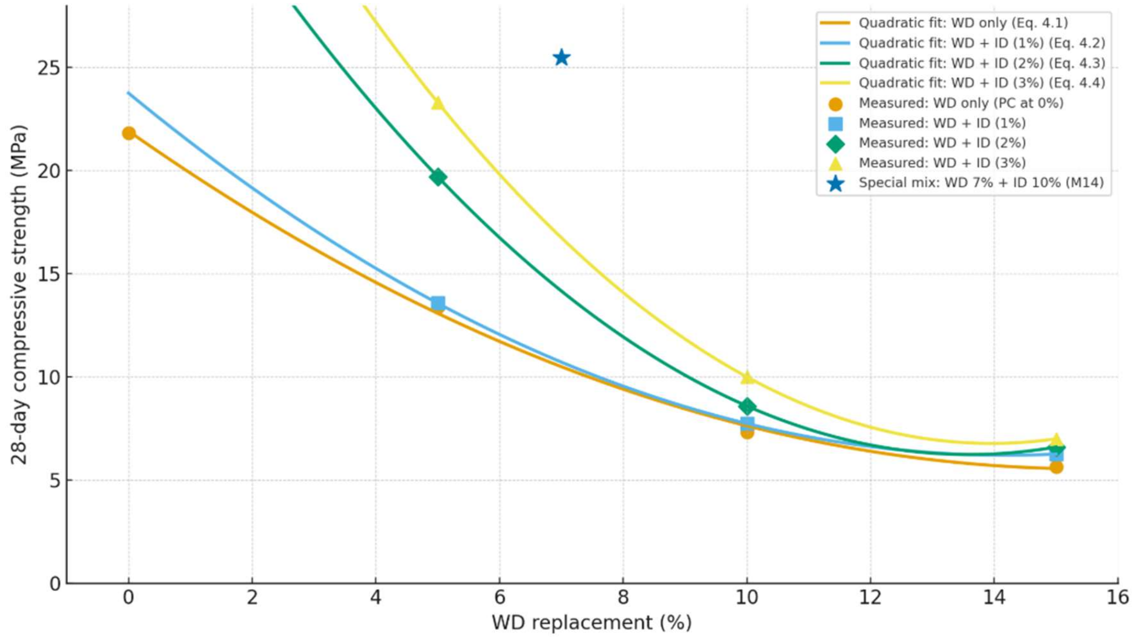

Fig.: Variation of 28-day compressive strength of concrete with WD replacement and ID addition.

Relation between compressive strength and % WD replacement

To provide a predictive representation of the trend within the tested range (0 – 15% WD), quadratic relations of the form $y = ax^2 + bx + c$ were fitted .

i. WD only (PC and WD = 5%, 10%, 15%):

$$\boxed{y = 0.0676x^2 - 2.1040x + 21.9100} \dots\dots\dots\dots (4.1)$$

ii. WD + ID (1% ID) (points at x = 5, 10, 15%):

$$\boxed{y = 0.0870x^2 - 2.4710x + 23.7500} \dots\dots\dots\dots (4.2)$$

iii. WD + ID (2% ID) (points at x = 5, 10, 15%):

$$\boxed{y = 0.1824x^2 - 4.9580x + 39.9300} \dots\dots\dots\dots (4.3)$$

iv. WD + ID (3% ID) (points at x = 5, 10, 15%):

$$\boxed{y = 0.2060x^2 - 5.7500x + 46.9000} \dots\dots\dots\dots (4.4)$$

Here, y = compressive strength (MPa) and x = (%) replacement of fine aggregate by WD. Equations (4.2) – (4.4) are exact quadratic fits through the three measured points for each ID level; equation (4.1) is a least-squares quadratic fit to the four measured points for the WD-only series (x = 0, 5, 10, 15%).

37 WD replacement produces a marked and monotonic reduction in 28-day compressive strength the strength fell from 21.81 MPa (PC) to 13.38 MPa at 5% WD, 7.33 MPa at 64 10% WD, and 5.66 MPa at 15% WD. The observed reduction is attributable to the porous and hygroscopic nature of wood dust which increases internal voids, raises water demand and weakens the cement aggregate interfacial zone.

Addition of ID to WD mixes partially counteracts the adverse effect of WD. For WD = 109 5% the inclusion of ID at 1%, 2% and 3% produced 28-day strengths of 13.57 MPa, 19.70 MPa and 23.30 MPa respectively; at 3% ID the strength exceeded the control. For higher WD levels (10% and 15%), ID improved strength slightly but could not restore it to control values at the tested dosages. This indicates that small ID dosages act as micro-fillers and improve particle packing and local matrix continuity, but their compensating effect is limited when WD-induced porosity becomes large.

137 A special mix (M14: WD 7% + ID 10%) yielded the highest 28-day strength of 25.49 MPa, i.e., 16.87% greater than PC. This demonstrates that appropriate WD–ID combinations can not only offset strength loss but also produce strength gains when the additive/filler balance is optimized.

Mix ID	Wood Dust (WD) %	28-day compressive strength (MPa)	Change from PC (MPa)	Percent change from PC (%)
M1	(control)	21.81	0.00	0.00
M2	5%	13.38	−8.43	−38.65
M3	10%	7.33	−14.48	−66.39
M4	15%	5.66	−16.15	−74.05
1% Iron Dust Included				
M5	5%	13.57	−8.24	−37.78
M6	10%	7.74	−14.07	−64.51
M7	15%	6.26	−15.55	−71.30
2% Iron Dust Included				
M8	5%	19.70	−2.11	−9.67
M9	10%	8.59	−13.22	−60.61
M10	15%	6.60	−15.21	−69.74
3% Iron Dust Included				

M11	5%	23.30	+1.49	+6.83
M12	10%	10.00	−11.81	−54.15
M13	15%	7.00	−14.81	−67.90
Special Mix				
M14	WD (7%) + ID (10%)	25.49	+3.68	+16.87

Table : Amount of change in compressive strength (28-day)

Partial replacement of fine aggregate by WD reduces 28-day compressive strength substantially; keep WD content low (≤ 5–7%) if strength preservation is required. ID functions effectively as a micro-filler/additive: at low WD (5%) ID at 2–3% can largely restore or even improve strength; at higher WD (10–15%) tested ID dosages are insufficient to recover control strength. Balanced WD–ID combinations (e.g., WD 7% + ID 10%) can yield strengths higher than the control, suggesting scope for optimization where both waste utilization and mechanical performance are targeted

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4.3.1 Compressive Capacity at Different Partial Replacement of Fine Aggregate with Wood Dust (WD)

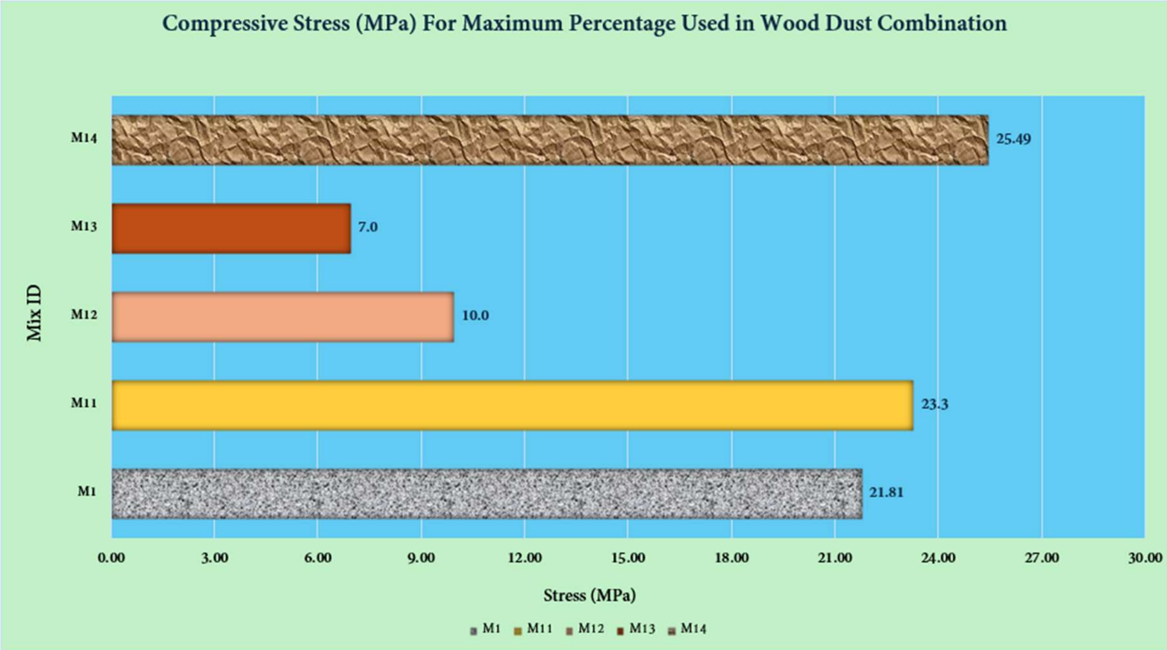

Fig : Comparison between Control mix (M1) Vs Other best and worst combinations at compressive stress .

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The 28-day compressive strength of the control mix (M1) was 21.81 MPa; partial replacement of fine aggregate with wood dust (WD) produced a clear, dose-dependent reduction in compressive capacity (PC+WD 5% = 13.38 MPa, −38.7% vs control; PC+WD 10% = 7.33 MPa, −66.4%; PC+WD 15% = 5.66 MPa, −74.1%). Incorporation of iron dust (ID) into selected mixes substantially mitigated these losses: for example, PC+WD(5%)+ID(3%) (M11) attained 23.30 MPa (+6.8% relative to control) and the special composition PC+WD(7%)+ID(10%) (M14) reached 25.49 MPa (+16.9% relative to control). These results indicate that while WD alone is detrimental to 28-day compressive performance at increasing replacement levels, appropriate dosing of ID can restore and even improve compressive strength beyond the unmodified control

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4.4 Effect of WD & ID on Splitting tensile strength of Concrete

In Fig. it can be observed that the 28-day splitting tensile strength of concrete decreases as the percentage of waste wood dust (WD) used to replace fine aggregate increases. Addition of iron dust (ID) to WD-containing mixes partially mitigates the strength loss, and the magnitude of recovery depends strongly on the ID dosage and the WD level. The numerical results for the tested mixes are summarized in Table and plotted in Fig.

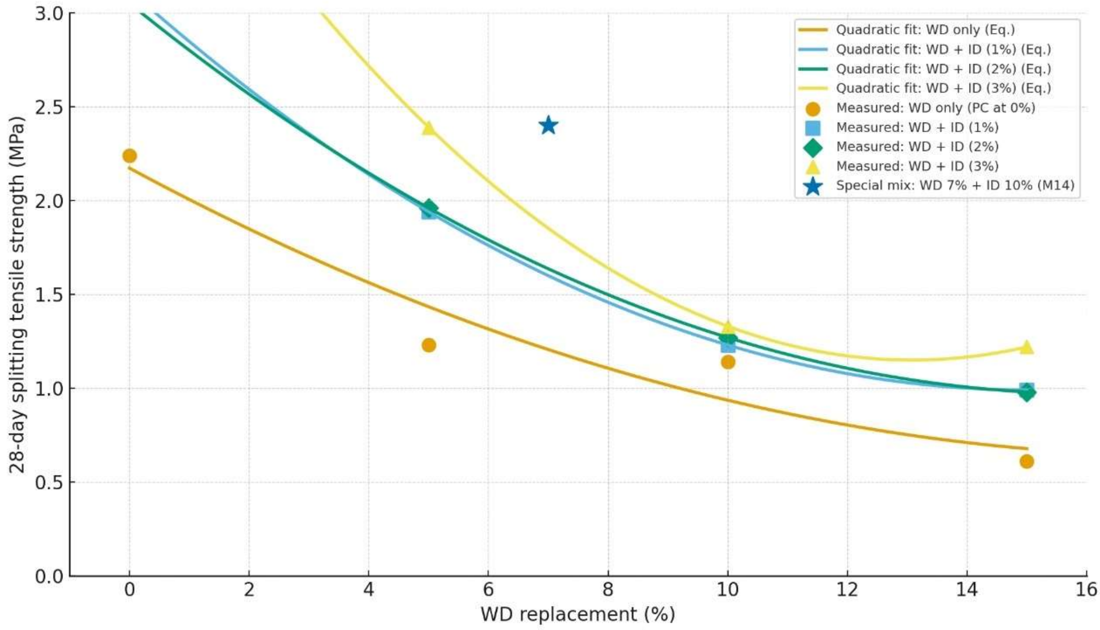

Fig. : Variation of 28-day splitting tensile strength of concrete with WD replacement and ID addition.

Relation between splitting tensile strength and % WD replacement

To describe the trend within the tested range (0–15% WD), quadratic relations of the form $y = ax^2 + bx + c$ were fitted, where x is the percentage (%) replacement of fine aggregate by WD and $y$is the 28-day splitting tensile strength (MPa).

i. WD only (PC and WD = 5%, 10%, 15%):

$$\boxed{y = 0.0048x^2 - 0.1716x + 2.1720} \dots\dots\dots\dots (4.5)$$

ii. WD + ID (1% ID) (points at $x = 5, 10, 15\%$):

$$\boxed{y = -0.0078x^2 + 0.0610x + 1.8300} \dots\dots\dots\dots (4.6)$$

iii. WD + ID (2% ID) (points at $x = 5, 10, 15\%$):

$$\boxed{y = 0.0080x^2 - 0.2580x + 3.0500} \dots\dots\dots\dots (4.7)$$

iv. WD + ID (3% ID) (points at $x = 5, 10, 15\%$):

$$\boxed{y = 0.0190x^2 - 0.4970x + 4.4000} \dots\dots\dots\dots (4.8)$$

Equations (4.6) – (4.8) are exact quadratic fits through the three measured points for each ID level; equation (4.5) is a least-squares quadratic fit to the four measured points for the WD-only series (x = 0, 5, 10, 15%).

WD replacement reduces splitting tensile strength. The replacement of fine aggregate by WD causes a clear reduction in 28-day splitting tensile strength from 2.24 MPa (PC) down to 1.23 MPa (5% WD), 1.14 MPa (10% WD) and 0.61 MPa (15% WD). The reduction is consistent with increased porosity, poorer aggregate–matrix bonding and the higher internal water demand of wood particles, which together weaken the tensile capacity of the matrix and the interfacial transition zone.

ID addition partially restores tensile capacity at low WD contents. For WD = 5% the inclusion of ID at 1% and 2% raised tensile strength to about 1.94–1.96 MPa, and at 3% ID the strength increased to 2.39 MPa (exceeding the control). This suggests ID can act as a micro-filler and may enhance microstructural packing and crack-bridging mechanisms at low WD replacement levels.

At higher WD levels (10–15%), ID yields limited recovery. For WD = 10% and 15% the improvements from ID (1–3%) were modest; strengths remained substantially below the control. These observations indicate that the damage introduced by higher WD contents (voids, weaker ITZ) cannot be fully mitigated by low dosages of ID alone.

Optimized WD & ID combinations can outperform the control. The special mix (M14: WD 7% + ID 10%) produced 2.40 MPa slightly higher than PC (2.24 MPa) indicating that an appropriate balance between waste replacement and metallic filler can yield both waste utilization and preserved (or improved) tensile properties.

Mix ID	**Wood Dust (WD) %**	**28-day splitting tensile strength (MPa)**	**Change from PC (MPa)**	**Percent change from PC (%)**
M1	(control)	2.24	0.00	0.00
M2	5%	1.23	−1.01	−45.09
M3	10%	1.14	−1.10	−49.11
M4	15%	0.61	−1.63	−72.77
1% Iron Dust Included				
M5	5%	1.94	−0.30	−13.39
M6	10%	1.23	−1.01	−45.09
M7	15%	0.99	−1.25	−55.80
2% Iron Dust Included				
M8	5%	1.96	−0.28	−12.50
M9	10%	1.27	−0.97	−43.30

M10	15%	0.98	−1.26	−56.25
3% Iron Dust Included				
M11	5%	2.39	+0.15	+6.70
M12	10%	1.33	−0.91	−40.63
M13	15%	1.22	−1.02	−45.54
Special Mix				
M14	WD (7%) + ID (10%)	2.40	+0.16	+7.14

Table : Amount of change in Splitting tensile strength (28-day)

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Partial replacement of fine aggregate by WD causes a significant reduction in 28-day splitting tensile strength; to preserve tensile performance, WD content should be kept low (≤ 5–7%). ID functions effectively as a micro-filler/additive: at low WD (5%) ID at 1–3% progressively restores tensile capacity and at 3% ID the tensile strength may exceed the control; at higher WD (10–15%) the tested ID dosages provide only limited recovery. Optimized WD – ID combinations (for, WD 7% + ID 10%) can yield splitting tensile strengths comparable to, or slightly higher than, the control, indicating scope for tuning the WD – ID balance to achieve both waste utilization and acceptable tensile performance.

5

4.3.1 Splitting Tensile Capacity at Different Partial Replacement of Fine Aggregate with Wood Dust (WD)

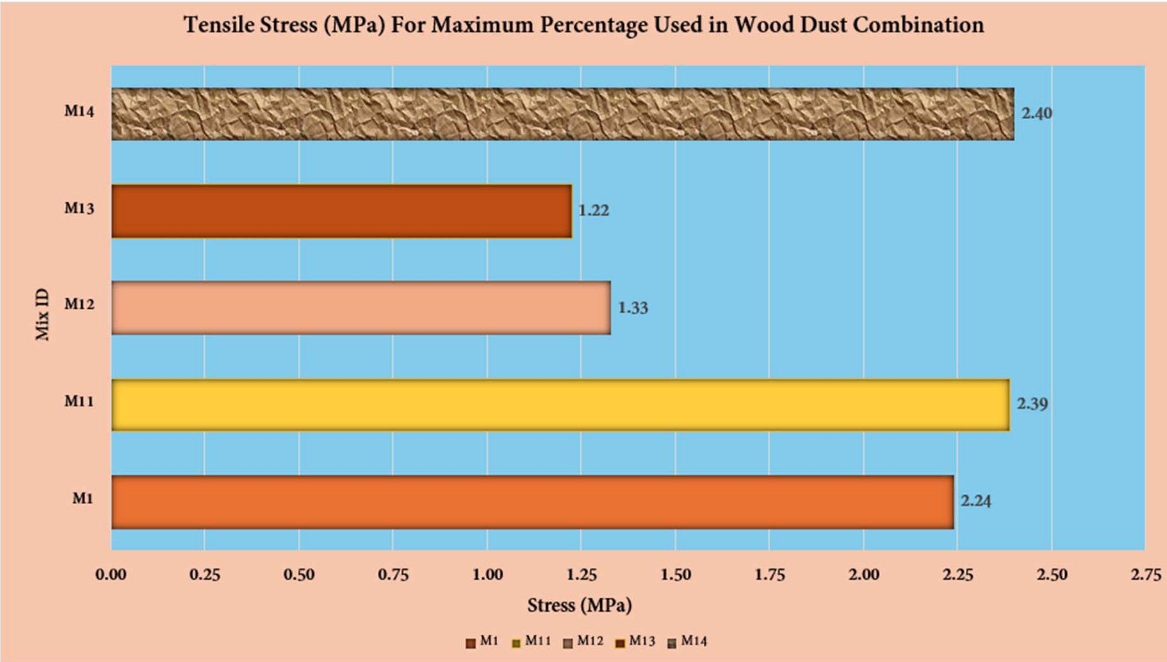

Fig : Comparison between Control mix (M1) Vs Other best and worst combinations at Splitting tensile stress .

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The control splitting tensile strength at 28 days (M1) was 2.24 MPa; substitution with WD caused marked reductions in tensile capacity (PC+WD 5% = 1.23 MPa, −45.1% vs control; PC+WD 10% = 1.14 MPa, −49.1%; PC+WD 15% = 0.61 MPa, −72.8%), whereas addition of ID improved tensile behaviour in several compositions most notably PC+WD(5%)+ID(3%) (M11) = 2.39 MPa (+6.7% vs control) and PC+WD(7%)+ID(10%) (M14) = 2.40 MPa (+7.1% vs control) showing that targeted ID supplementation can effectively compensate for the tensile strength loss induced by WD .

4.5 Failure and cracking patterns

Specimens with increasing WD content displayed progressively different failure appearances:

- **Control specimens** fractured as classic, narrow splitting planes (brittle failure).

Fig, :Control specimens compressive & splitting tensile strength test (brittle) failure.

- **Low–moderate WD (5–10%)** produced more tortuous crack paths and evidence of particle pull-out around wood inclusions. The peak load dropped but crack propagation exhibited more micro-branching and greater energy absorption before final failure (less "clean" brittle fracture).

Fig, :M11 and M12 specimen under compressive & splitting tensile strength test failure

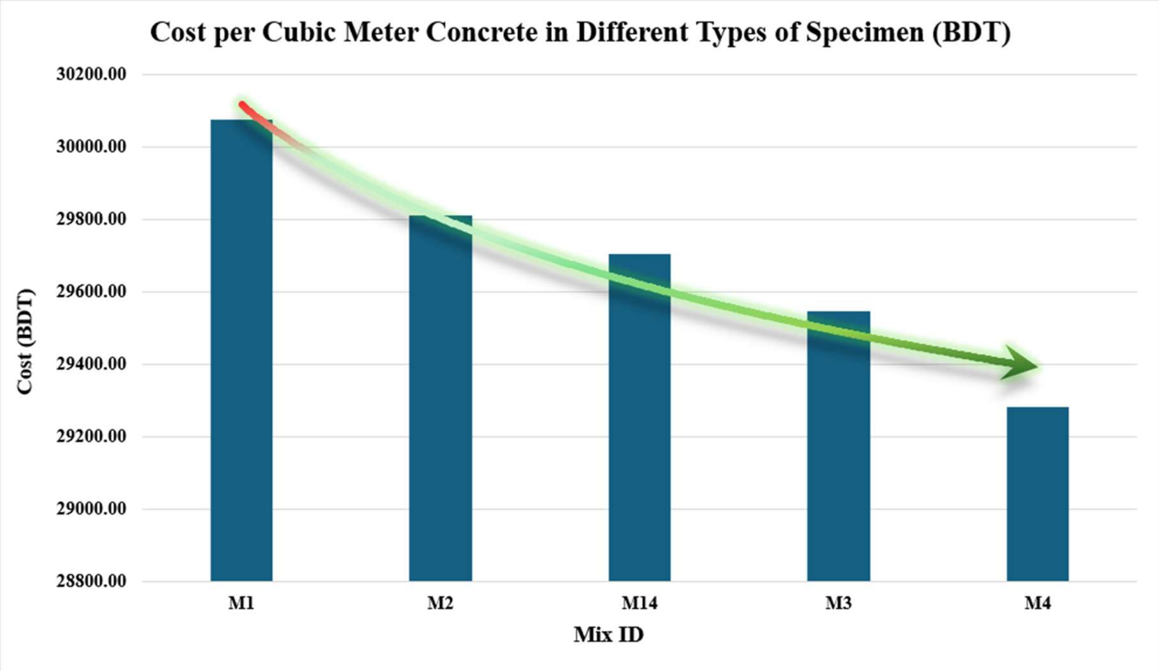
- **High WD (15%)** specimens failed at much lower loads and showed smeared fracture zones with multiple small cracks rather than a single clean split.

Fig, : M4 specimen under compressive & splitting tensile strength test failure

Adding ID reduced the incidence of large, through-width separations: micro-filled matrices showed tighter crack widths and less spalling at the fracture surface. The qualitative observation is that ID helps to narrow crack openings and shift failure toward a less catastrophic mode a positive safety feature for some applications while peak capacity is the critical metric for load-bearing design.

4.6 Cost Analysis of Different Mixes

The column chart (M1–M4 plus M14) demonstrates two concurrent trends first
121 progressive reduction of unit material cost as waste wood dust (WD) replaces a portion of the fine aggregate (M1 → M4), and secondly, the potential for an optimized WD–ID (iron dust) combination (M14) to deliver both cost efficiency and improved mechanical performance relative to the control. While M2–M4 achieve measurable cost savings by
33 lowering sand consumption, they incur substantial reductions in 28-day compressive and splitting tensile strength. Mix M14 (PC + WD 7% + ID 10%) is distinct: it attains higher compressive and tensile strengths than the control while remaining cost-competitive making it a promising candidate for applications requiring both light-weight structural adequacy and resource savings .



Fig, : Cost analysis chart at different specimen type .

Cost behaviour (M1 → M4): Unit material cost per cubic meter (m^3) decreases monotonically as WD content increases from 0% to 15%. This lowering of direct material cost is driven primarily by reduced natural sand demand and the assumption that WD is a low-cost waste input. The column chart for M1–M4 clearly visualizes this trend.

Optimized WD–ID effect (M14): Mix M14 (WD 7% + ID 10%) reverses the performance loss: it shows compressive and splitting tensile strengths that exceed the control while maintaining a unit cost comparable to the original mix. This demonstrates that an appropriately designed metallic filler can improve particle packing and microstructural integrity, enabling both waste utilization and mechanical improvement.

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CHAPTER V

CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

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- ✓ The study demonstrates that partial replacement of fine aggregate with waste wood powder (WD) substantially affects both fresh and hardened behaviour WD reduces slump and lowers 28-day compressive and splitting tensile strengths in a dose-dependent manner.
- ✓ Waste iron dust (ID), used at low dosages (3%), functions effectively as a micro-filler it improves particle packing and can partially and in some formulated cases fully compensate for strength losses introduced by WD.
- ✓ Modest WD substitutions (PC with 5% replacement of fine aggregate (WD) and with 3% waste iron dust (ID) as an additive material) offer a favorable sustainability performance trade-off; beyond moderate replacement levels the mechanical penalty becomes large and limits structural use unless compensated.
- ✓ The combined application of WD and ID (carefully proportioned) offers a practical valorization pathway the laboratory data indicate that selected combined mixes can achieve both substantial (WD (7%) + ID (10%)) use of waste materials and acceptable mechanical performance.
- ✓ Reproducible performance depends critically on material conditioning and mix-control (WD water absorption and uniform ID preprocessing with strict batching and curing).
- ✓ The per-cubic-meter cost reductions observed for M2–M4 compound significantly with volume in large projects the cumulative savings are substantial under the assumption that WD is available at low cost. Illustratively, these economies of scale make WD substitution particularly attractive for high-volume, low-demand uses.

- ✓ The net cost advantage depends critically on preprocessing, transport, handling and storage of WD. If WD requires drying, sieving or contamination control, these operational costs may offset a portion of the material savings. Realistic project budgeting must incorporate these factors.

- ✓ Reduced initial material cost may be offset over time by increased maintenance if durability issues (shrinkage, biodegradation potential, increased permeability) are not mitigated. Include accelerated durability testing and long-term monitoring in implementation plans.

5.2 Recommendations (practical and prioritized)

- ❖ **Adopt conservative WD limits for load-bearing elements:** For projects seeking structural reliability, restrict WD replacement to the low end of tested ranges and validate by project-specific tests.

- ❖ **Pre- saturation of wood dust (WD) :** Before casting concrete the wood dust (WD) should be soaked in water so the wood dust will not able to absorb water from concrete during hydration reaction, because of this process the workability /slump value won't be disturb .

- ❖ **Use ID as an engineering compensator:** Where WD is necessary for sustainability goals, include low-dose ID (as shown effective in this work) to restore packing and strength, but validate with local materials and repeat tests.

- ❖ **WD moisture control in batching:** Implement SSD pre-conditioning or record-and-deduct moisture procedures for WD so effective w/c is stable across batches.

- ❖ **Quality-assure ID supply:** Require supplier checks for contamination, particle-size consistency and appropriate cleaning to avoid batch variability or adverse durability effects.

- ❖ **Pilot before scale-up:** Trial the most promising mixes (e.g., 5%WD + 3%ID and the 7% WD + 10% ID) in a pilot production run with expanded replication and performance verification (including cast elements).

- **Use conservative design margins:** Until wider datasets are available, apply conservative characteristic strengths (not simply mean values) when using WD/ID mixes in design.

- **Further research priorities:** (a) Beam/element-level structural tests to confirm load-path behaviour;(b) Longer-term curing and durability monitoring under relevant exposures;(c) Life-cycle and economic assessment to quantify sustainability gains.;(d) Define more prese sized percentage for suitable real-life application .

- **Long Term Development:** Mechanical data are 28-day values; longer-term strength development and durability properties were should be included in analysis and examined before large scale application.

- **Waste Handling:** Local environmental and regulatory constraints (e.g., organic waste handling, fire safety, leachate control) must be satisfied before large-scale adoption.

5.3 Final statement

This research show WD that valorizing wood and iron industrial wastes in concrete is not only technically feasible but also strategically promising: with disciplined material control and modest, evidence-based use of iron dust (ID), it is possible to transform two waste streams into functional, lower-impact construction materials. The path from laboratory success to reliable field deployment requires the quality controls and pilot validations recommended above steps that will turn promising experimental outcomes into reproducible, industry-ready practice.

The inclusion of waste wood dust (WD) as a partial fine-aggregate replacement reduces unit material cost per cubic meter, a trend that becomes pronounced at higher replacement levels and is visually apparent in the M1–M4 column chart. However, WD replacement also causes a marked deterioration of both 28-day compressive and splitting tensile strengths. Significantly, an optimized WD–ID combination (M14: WD 7% + ID 10%) achieved compressive and tensile strengths that exceed the control while remaining cost-competitive; this mix therefore represents a practical, budget-friendly alternative for applications that require light-weight structural performance alongside waste utilization. For structural elements, WD should be limited to low percentages (≤

5–7%) and combined with corrective additives; for non-structural and large-volume uses, higher WD contents (10–15%) provide meaningful cost savings provided appropriate preprocessing and durability controls are implemented. Implementation decisions should be based on full lifecycle cost modelling and site-specific logistics.

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REFERENCES

- ASTM International. (2021). *ASTM C150/C150M-21: Standard specification for Portland cement*. West Conshohocken, PA: ASTM International. https://www.astm.org/c0150_c0150m-21.html
- ASTM International. (2018). *ASTM C33/C33M-18: Standard specification for concrete aggregates*. West Conshohocken, PA: ASTM International. https://www.astm.org/c0033_c0033m-18.html
- ASTM International. (2020). *ASTM C39/C39M-20: Standard test method for compressive strength of cylindrical concrete specimens*. West Conshohocken, PA: ASTM International. https://www.astm.org/c0039_c0039m-20.html
- ACI Committee 211. (1991). *Standard practice for selecting proportions for normal, heavyweight, and mass concrete (ACI 211.1-91)*. American Concrete Institute. https://www.concrete.org/
- ASTM International. (2020). *ASTM C1585-20: Standard test method for measurement of rate of absorption of water by hydraulic-cement concretes (sorptivity)*. West Conshohocken, PA: ASTM International. https://www.astm.org/c1585-20.html
- ASTM International. (2021). *ASTM C642-21: Standard test method for density, absorption, and voids in hardened concrete*. West Conshohocken, PA: ASTM International. https://www.astm.org/c0642-21.html
- Abdullahi, M., Al-Mattarneh, H. A., & Oyejobi, D. O. (2013). Exploratory study of sawdust as partial replacement for sand in concrete. *International Journal of Engineering Research and Applications, 3*(4), 1119–1121.
- Ahmed, H. U., Mahmud, M. A. P., & Bhuiyan, M. A. A. (2018). Use of sawdust in concrete: A review. *Construction and Building Materials, 167*, 372–381.
- Alom, M. S. (2014a). Properties of recycled concrete aggregate. *Journal of Materials in Civil Engineering, 26*(1), 134–140.

- Alom, M. S. (2014b). Environmental impact of aggregate replacement. *International Journal of Environmental Engineering, 6*(2), 90–95.
- Beiser, V. (2015). *The world in a grain: The story of sand and how it transformed civilization*. Riverhead Books.
- Habib, M. A., & Hassan, R. (2015). Recycling polyethylene waste in concrete production. *Waste Management & Research, 33*(4), 342–349.
- Kothai, P. S., & Malathy, R. (2015). Experimental study on strength of concrete using iron powder as a partial replacement of cement. *International Journal of Innovative Research in Science, Engineering and Technology, 4*(5), 2783–2787.
- Rashid, M. (2005). Durability and performance of concrete with alternative aggregates. *Proceedings of the Institution of Civil Engineers – Structures and Buildings, 158*(5), 251–260.
- Ramesh, K., Kumar, D., & Prasad, S. S. (2020). Effect of iron filings in concrete. *Materials Today: Proceedings, 28*, 1236–1240.
- Yakubu, D., & Bukar, M. A. (2020). Effects of sawdust as fine aggregate replacement on the properties of concrete. *Nigerian Journal of Technology, 39*(2), 460–467.
- World Economic Forum. (2023, September). Global sand mining is reshaping the world – and our lives. World Economic Forum. https://www.weforum.org/stories/2023/09/global-sand-mining-demand-impacting-environment/
- Cabanillas-Hernández, M. A., Flores, L., Mendoza, J., Herrera, M., Carrillo, A., & Espinoza, E. (2024). Concrete composites with sawdust. *Asian Journal of Civil Engineering, 25*, 1509–1524. https://doi.org/10.1007/s41062-024-01567-6
- Ekop, I. E., Arum, C., Nwoji, C., Okoli, O. I., & Eyo, I. E. (2022). Comparative study on recycled iron filings and glass powder as fine aggregate. *Case Studies in Construction Materials, 16*, e01048. https://doi.org/10.1016/j.cscm.2022.e01048

- Ghannam, S., Najm, H., & Vasconez, R. (2016). Experimental study of concrete made with granite and iron powders as partial replacement of sand. *Sustainable Materials and Technologies, 9*, 1–9. https://doi.org/10.1016/j.susmat.2016.06.001

- Hernández-Ocaña, B., López-Perales, J. F., Gómez-Soberón, J. M., Corral-Higuera, R., Arredondo-Rea, S. P., & Almaral-Sánchez, J. L. (2022). Assessment of woodcrete by NDT and mechanical testing. *Buildings, 12*(8), 1277. https://doi.org/10.3390/buildings12081277

- Largeau, M. A., Mutuku, R., & Thuo, J. (2018). Effect of iron powder (Fe_2O_3) on strength, workability, and porosity of binary blended concrete. *Open Journal of Civil Engineering, 8*(4), 411–425. https://doi.org/10.4236/ojce.2018.84029

- Maglad, A. M., Shafigh, P., Lawan, I., & Ibrahim, Z. (2023). Experimental study of the flexural behaviour of RC beams made of eco-friendly sawdust concrete and strengthened by a wooden plate. *International Journal of Concrete Structures and Materials, 17*, 51. https://doi.org/10.1186/s40069-023-00617-0

- Miah, M. J., Alam, M. S., Hoque, M. N., Islam, M. S., & Islam, M. R. (2020). Effect of recycled iron powder as fine aggregate on the mechanical properties and drying shrinkage of mortar. *Materials, 13*(5), 1146. https://doi.org/10.3390/ma13051146

- Siddique, R., Mehta, A., Jamal, A., & Belarbi, R. (2020). Utilization of treated sawdust in concrete as partial replacement of sand. *Journal of Cleaner Production, 261*, 121226. https://doi.org/10.1016/j.jclepro.2020.121226

- Thakur, A. K., Singh, R., & Chittora, M. K. (2023). Waste sawdust as partial replacement of fine aggregate in cement mortars. *IOP Conference Series: Materials Science and Engineering, 1144*, 012027. https://doi.org/10.1088/1757-899X/1144/1/012027

- Turgut, P. (2007). Cement composite with limestone dust and different grades of wood sawdust. *Building and Environment, 42*(10), 3801–3807. https://doi.org/10.1016/j.buildenv.2006.08.012

- Waqar, A., Khan, M. B., Najeh, T., Mugahed Amran, Y. H., Fediuk, R., & Vatin, N. I. (2024). Performance-based engineering: Formulating sustainable concrete with sawdust and steel fiber. *Frontiers in Materials, 11*, 1428700. https://doi.org/10.3389/fmats.2024.1428700

- United Nations Environment Programme (UNEP). (2023). *Sand and sustainability: 10 strategic recommendations to avert a crisis*. UNEP. https://www.unep.org/resources/report/sand-and-sustainability-10-strategic-recommendations-avert-crisis

- Ali, M. S., Khan, I. A., & Hossain, M. I. (2008). Chemical analysis of ordinary Portland cement of Bangladesh. *Chemical Engineering Research Bulletin, 12*, 7–10.

- ASTM International. (2022). *ASTM C150/C150M-22: Standard specification for Portland cement*. West Conshohocken, PA: ASTM International.

- Bogue, R. H. (1955). *The chemistry of Portland cement* (2nd ed.). Reinhold Publishing Corporation.

- British Standards Institution. (1991). *BS 12:1991 Specification for Portland cement*. London: BSI.

- Neville, A. M. (1996). *Properties of concrete* (4th ed.). Pearson.

- Taylor, H. F. W. (1964). *The chemistry of cements* (Vol. 1). Academic Press.

- Fadiel, A., & Abu-Lebdeh, T. (2021). Mechanical properties of concrete including wood shavings as fine aggregates. *American Journal of Engineering and Applied Sciences, 14*(4), 478–487.

- Abed, A., et al. (2019). Sawdust/wood-waste in concrete blocks: Physical and mechanical behavior. *International Journal of Integrated Engineering, 11*(8), 229–239.

- Krausmann, F., Wiedenhofer, D., Lauk, C., Haas, W., Tanikawa, H., Fischman, T., Miatto, A., Schandl, H., & Haberl, H. (2017). Global socioeconomic material stocks rise 23-fold over the 20th century and require half of annual resource use. *Proceedings of the National Academy of Sciences, 114*(8), 1880–1885. https://doi.org/10.1073/pnas.1613773114

- Miah, M. J., Tareq, M., et al. (2020). Effect of recycled iron powder as fine aggregate on the mechanical and durability properties of mortar exposed to elevated temperatures. *Materials, 13*(5), 1168. https://doi.org/10.3390/ma13051168

- United Nations Environment Programme (UNEP). (2019). *Sand and sustainability: Finding new solutions for environmental governance of global sand resources*. GRID-Geneva, UNEP. https://www.unep.org/resources/report/sand-and-sustainability-finding-new-solutions-environmental-governance-global-sand

- BBC Future. (2019, November 8). Why is the world running out of sand? https://www.bbc.com/future/article/20191108-why-the-world-is-running-out-of-sand

- Meredith, S. (2021, March 5). A sand shortage? The world is running out of a crucial — but under-appreciated — commodity. *CNBC*. https://www.cnbc.com/2021/03/05/sand-shortage-the-world-is-running-out-of-a-crucial-commodity.html

- Dias, S., Hernández-Ocaña, B., López-Perales, J. F., Gómez-Soberón, J. M., Corral-Higuera, R., Arredondo-Rea, S. P., & Almaral-Sánchez, J. L. (2022). Physical, mechanical, and durability properties of concrete containing wood chips and sawdust: An experimental approach. *Buildings, 12*(8), 1277. https://doi.org/10.3390/buildings12081277

- Bourzik, O., Akkouri, N., Baba, K., & Nounah, A. (2022). Study of the effect of wood waste powder on the properties of concrete. *Materials Today: Proceedings, 58*, 1459–1463. https://doi.org/10.1016/j.matpr.2022.02.518

- Olaiya, B. C. (2023). Utilization of sawdust composites in construction — a review. *SN Applied Sciences, 5*, 5361. https://doi.org/10.1007/s42452-023-05361-4

- Inbanila, T., & Priyadharshini, D. (2019). Effect of iron powder on strength of binary blended concrete. *International Journal of Recent Technology and Engineering (IJRTE), 8*(3), 2490–2492. https://doi.org/10.35940/ijrte.C4704.098319

- Li, W., Luo, Z., Long, C., Wu, C., Duan, W. H., & Shah, S. P. (2022). Effects of nanoparticle on the dynamic behaviors of recycled aggregate concrete under impact loading: A review. *Construction and Building Materials, 350*, 129421. https://doi.org/10.1016/j.conbuildmat.2022.129421

- Watari, T., Böcher, C., Baumgart, A., Ljunge, J., & Wiedenhofer, D. (2025). Mapping sand flows and stocks. *One Earth, 8*, 101197. https://doi.org/10.1016/j.oneear.2025.101197

- Plank, B., Streeck, J., Virág, D., Krausmann, F., Haberl, H., & Wiedenhofer, D. (2022). Compilation of an economy-wide material flow database for 14 stock-building materials in 177 countries from 1900 to 2016. *MethodsX, 9*, 101654. https://doi.org/10.1016/j.mex.2022.101654

- Katz-Lavigne, S., Pandey, S., & Suykens, B. (2022). *Mapping global sand: Extraction, research and policy options*. Conflict Research Group, University of Antwerp. https://repository.uantwerpen.be/docman/irua/1428b3/183490cc.pdf

- Sumarno, A., & Fitriawan, L. F. (2021). The effect of sawdust as substitution of fine aggregate on compressive strength of concrete. *International Journal of Civil Engineering, 6*(2), 81–88. https://pdfs.semanticscholar.org/826d/44f16f37d4fdba91544da31dd690acd01527.pdf

- Motaghed, S., Farhadi Ghafi, A., & Dadpour, A. (2022). Investigating the effect of iron ore powder on fresh and hardened properties of self-compacting concrete. *Advance Researches in Civil Engineering, 4*(4), 16–25.

- Al-Amin, M., & Hossain, Z. (2024). Manufacturing concrete with recycled iron as a partial replacement of fine aggregate. In *Proceedings of the 1st World Congress on Industrial Engineering and Operations Management* (pp. 420–430). IEOM Society International. https://doi.org/10.46254/WC01.20240160

- ASTM International. (2022). *ASTM C143: Standard test method for slump of hydraulic-cement concrete*. West Conshohocken, PA: ASTM International.

- ASTM International. (2022). *ASTM C31: Standard practice for making and curing concrete test specimens in the laboratory*. West Conshohocken, PA: ASTM International.

- ASTM International. (2022). *ASTM C496: Standard test method for splitting tensile strength of cylindrical concrete specimens*. West Conshohocken, PA: ASTM International.

- ASTM International. (2022). *ASTM C138: Standard test method for density and unit weight of concrete*. West Conshohocken, PA: ASTM International.
- Bentz, D. P., Garboczi, E. J., & Snyder, K. A. (2008). Permeability of cementitious materials: Relationships to microstructure. *Journal of Materials in Civil Engineering, 20*(6), 296–304. https://doi.org/10.1061/(ASCE)0899-1561(2008)20:6(296)
- Mehta, P. K., & Monteiro, P. J. M. (2014). *Concrete: Microstructure, properties, and materials* (4th ed.). McGraw-Hill.
- Neville, A. M. (2012). *Properties of concrete* (5th ed.). Pearson Education.
- Rashid, M. I., Ibrahim, M. F., & Raza, H. (2017). Use of industrial waste in concrete: A review. *Journal of Cleaner Production, 142*, 1353–1372. https://doi.org/10.1016/j.jclepro.2016.08.092
- Siddique, R., & Klaus, J. (2009). Effect of used foundry sand on the properties of concrete. *Journal of Hazardous Materials, 168*(2–3), 1307–1314. https://doi.org/10.1016/j.jhazmat.2009.03.014
- Li, X., & Cao, M. (2024). Recent developments on the effects of micro- and nano-limestone on the hydration process, products, and kinetics of cement. *Materials, 17*(9), 2133. https://doi.org/10.3390/ma17092133
- Cao, M., Ming, X., He, K., Li, L., & Shen, S. (2019). Effect of macro-, micro- and nano-calcium carbonate on properties of cementitious composites — A review. *Materials, 12*(5), 781. https://doi.org/10.3390/ma12050781
- Zhang, N., Zuo, W., Xu, W., & Song, S. (2020). A new approach for designing fluid concrete with low cement content: Optimization of packing density of aggregates. *Materials, 13*(18), 4082. https://doi.org/10.3390/ma13184082
- Juhart, J., Autischer, M., Sakoparnig, M., & Krüger, M. (2021). The realization of clinker-reduced, performance-based sustainable concrete by the micro-filler, eco-filler concept. *Materials, 14*(17), 4958. https://doi.org/10.3390/ma14174958

- Niewiadomski, P., Karolak, A., Stefaniuk, D., Królicka, A., Szymanowski, J., & Sadowski, Ł. (2021). Cement paste mixture proportioning with particle packing theory: An ambiguous effect of microsilica. *Materials, 14*(22), 6970. https://doi.org/10.3390/ma14226970

- Largeau, M. A., Mutuku, R., & Thuo, J. (2018). Effect of iron powder on strength, workability and porosity of binary-blended concrete. *Open Journal of Civil Engineering, 8*, 411–425. https://doi.org/10.4236/ojce.2018.84029

- Miah, M. J., Islam, M. A., Hasan, M. N., Rahman, M. M., & Hossain, M. (2020). Effect of recycled iron powder as fine aggregate on mechanical and durability behaviour. *Materials, 13*(5), 1168. https://doi.org/10.3390/ma13051168

APPENDIX A

Table A1: Name and details of the instruments

Name of Instruments	Details of the Instruments
Mixing Machine	Technotest, Capacity 350L, volts: 220/240, made in Italy
Compression Testing Machine	Model: UTM 100, Capacity: 3000 kN, Fuel Instruments & Engineers Pvt. Ltd., India

Table A2: Grading of Fine Aggregates

Total Sample Taken (gm) = 1000

ASTM C136 Sieve Analysis of Fine Aggregates					
Sieve Number	**Sieve size (mm)**	**Material Retained (gm)**	**%Material Retained**	**Cumulative % Retained**	**Cumulative % Passing**
3/8 in	9.5	0	0	0	100
#4	4.75	0	0	0	100
#8	2.36	56	5.60	5.60	94.4
#16	1.18	166	16.60	22.20	77.8
#30	0.6	426	42.60	64.80	35.2
#50	0.3	125	12.50	77.30	22.7
#100	0.15	214	21.40	98.70	1.3
pan	-	13	1.30	100	0
	Total (gm)	**1000**	Total	268.6	
Fineness Modulus	**2.7**				

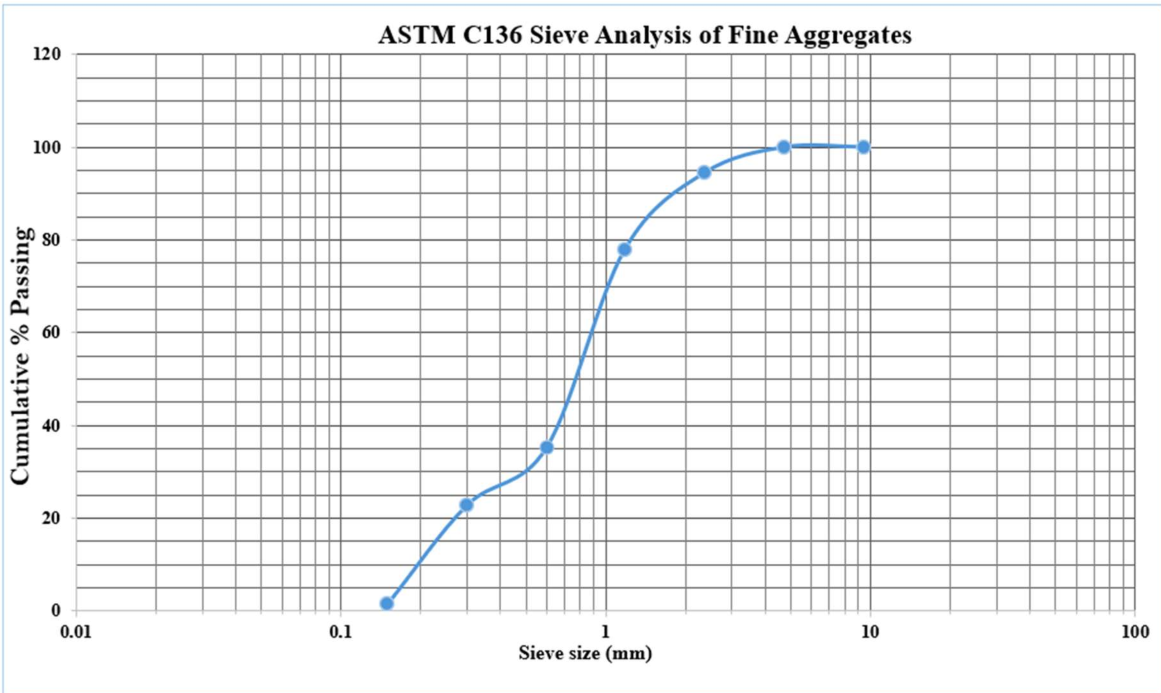

Table A : Grading of Coarse Aggregates

Total Sample Taken (gm) = 2000

ASTM C136 Sieve Analysis of Coarse Aggregates					
Sieve Number	**Sieve size (mm)**	**Material Retained (gm)**	**%Material Retained**	**Cumulative % Retained**	**Cumulative % Passing**
3 in	76.2	0	0.00	0.00	100.00
1.5 in	38.1	0	0.00	0.00	100.00
3/4 in	19.05	285	14.25	14.25	85.75
3/8 in	9.5	1389	69.45	83.70	16.30
#4	4.75	309	15.45	99.15	0.85
#8	2.36	17	0.85	100.00	0.00
#16	1.18	0	0.00	100.00	0.00
#30	0.6	0	0.00	100.00	0.00
#50	0.3	0	0.00	100.00	0.00
#100	0.15	0	0.00	100.00	0.00
	Total (gm)	**2000**	Total	**697.10**	
Fineness Modulus	**7**				

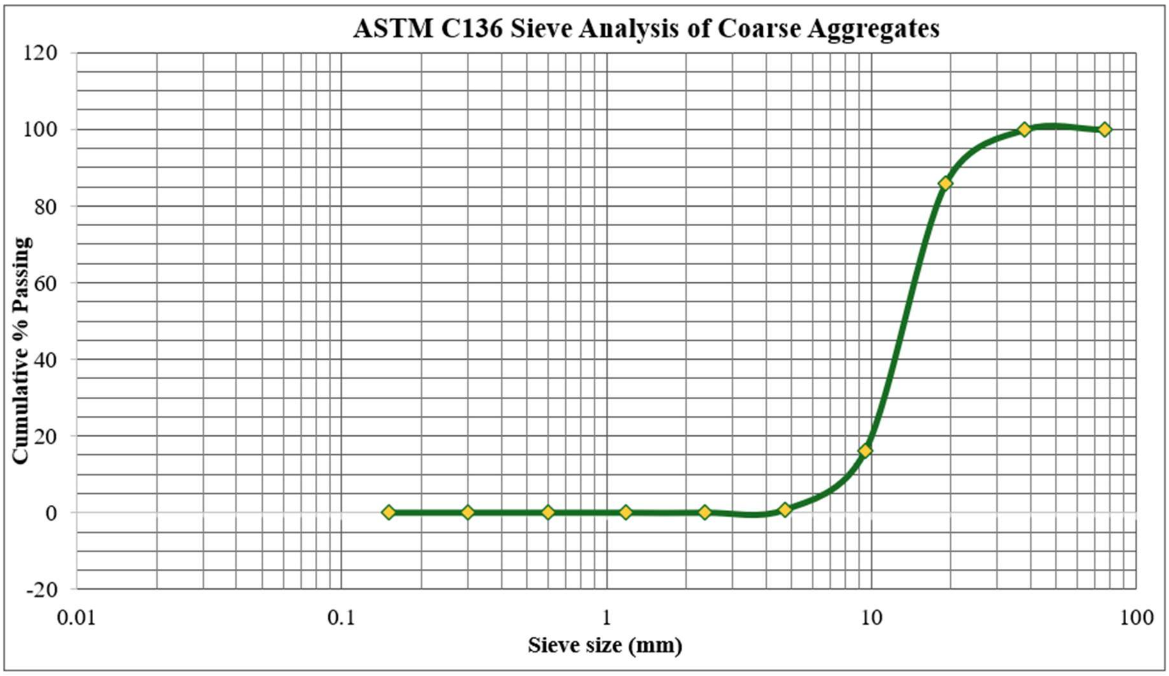

Table A : Grading of Wood Dust (WD) (Fine Aggregate Replace material)

Total Sample Taken (gm) = 500

ASTM C136 Sieve Analysis of Waste wood powder /Wood Dust (WD) (Fine Aggregate Replace material)					
Sieve Number	**Sieve size (mm)**	**Material Retained (gm)**	**%Material Retained**	**Cumulative % Retained**	**Cumulative % Passing**
3/8 in	9.5	0	0	0	100
#4	4.75	0	0	0	100
#8	2.36	0	0	0.00	100.0
#16	1.18	166	33	33.20	66.8
#30	0.6	32	6	39.60	60.4
#50	0.3	73	15	54.20	45.8
#100	0.15	229	46	100.00	0.0
pan	0	0	0	100	0.0
	Total (gm)	**500**	Total =	227.0	
Fineness Modulus	2.27				

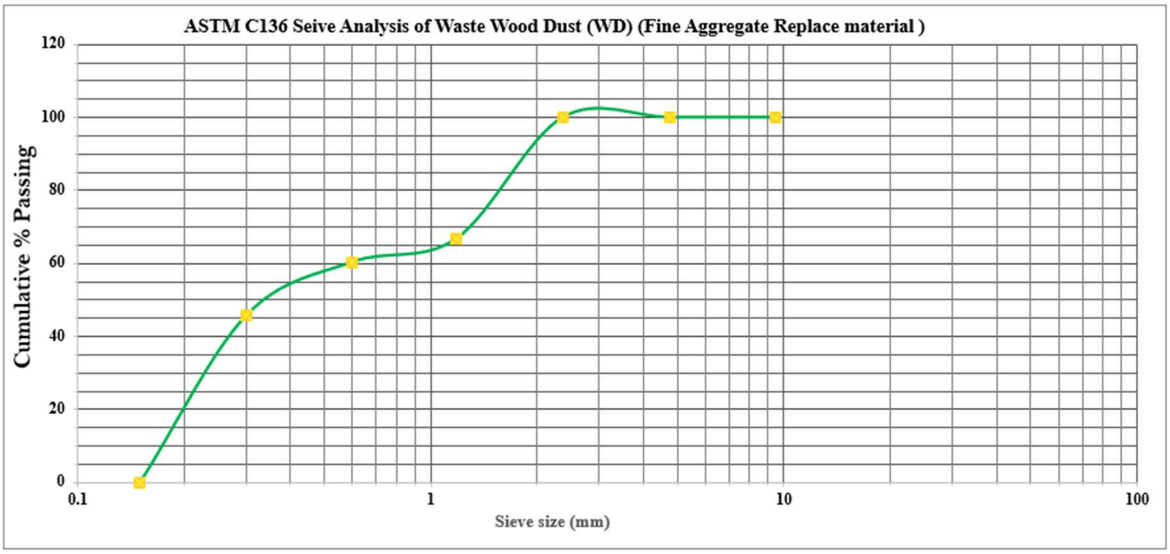

Table A : Grading of Iron Dust (ID)

Total Sample Taken (gm) = 1000

ASTM C136 Sieve Analysis of Iron Dust					
Sieve Number	Sieve size (mm)	Material Retained (gm)	%Material Retained	Cumulative % Retained	Cumulative % Passing
3/8 in	9.5	0	0	0	100
#4	4.75	0	0	0	100
#8	2.36	0	0.00	0.00	100.0
#16	1.18	0	0.00	0.00	100.0
#30	0.6	8	0.80	0.80	99.2
#50	0.3	28	2.80	3.60	96.4
#100	0.15	702	70.20	73.80	26.2
#200	0.075	44	4.40	78.20	21.8
pan	0	218	21.80	100.00	0.0
	Total (gm) =	**1000**	Total =	78.20	
Fineness Modulus	2.27				

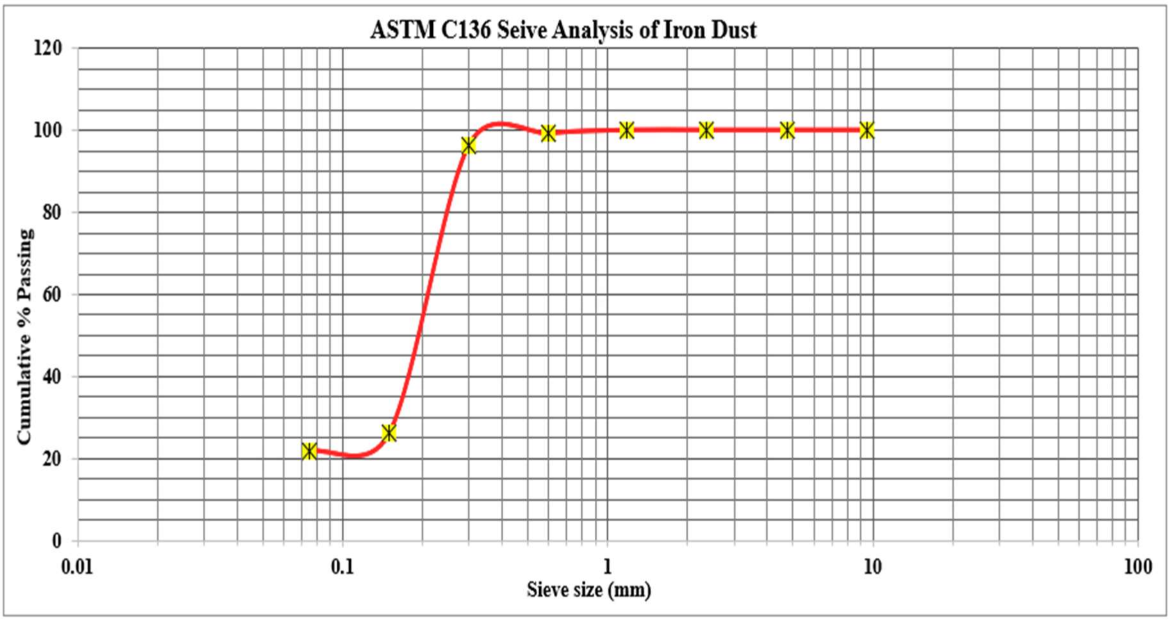

Table A : Bulk Density Test of Coarse Aggregate

Description	Value
Weight of aggregate, W (kg)	4.625
Volume measure, V (m^3)	0.00278
Bulk Density, (kg/m^3)	1663.67

Table A : Bulk Density Test of Fine Aggregate

Description	**Value**
Weight of aggregate, W (kg)	4.535
Volume measure, V (m^3)	0.00278
Bulk Density, (kg/m^3)	1631.30

Table A : Bulk Density Test of Wood Dust (WD)

Description	Value
Weight of Wood Dust , W (kg)	**0.741**
Volume measure, V (m3)	**0.002780006**
Bulk Density, **(kg/m3)**	**266.43**
Bulk Density **(kg/ft³)**	**7.54**

Table A : Bulk Density Test of Iron Dust (ID)

Description	Value
Weight of aggregate, W (kg)	**5.306**
Volume measure, V (m3)	**0.002780006**
Bulk Density, **(kg/m3)**	**1908.51**
Bulk Density **(kg/ft³)**	**54.04**

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Table A: Specific gravity & Absorption capacity of fine aggregate

Wt. of OD Sand A (g)	Wt. of Pycnometer + water B (g)	Wt. of Pycnometer + water + Sand C (g)	Wt. of SSD Sand S (g)	Sp. Gr.	Absorption (%)
1000	1231	1263	51	2.677	2

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Table A: Specific gravity & Absorption capacity of coarse aggregate

Wt. of C.A (Initial) A (g)	Wt. of C.A Under-water B (g)	Wt. of C.A in SSD Condition C (g)	Saturated Weight of C.A (gm)	OD Condition of C.A (gm)	Sp. Gr.	Absorption (%)
5000	3280	2034	5081	2000	2.776	1.7

Table A: Specific gravity of Wood Dust & Iron Dust (ID)

Material	Ws (gm)	W1 (gm)	W2 (gm)	S.G at 30 °C	S.G at 20 °C
Wood Dust (W.D)	50	1263	1233	2.5	2.494
Iron Dust (I.D)	50	1273	1233	5	4.989

Table A : Unit Weight of Different Mix

Mix ID	Mass (kg)	Diameter (mm)	Height (mm)	Volume (m³)	Unit weight (kg/m³)
M1	3.727	99.827	200.328	0.001568	2377
M2	3.546	99.638	201.389	0.00157	2258.2
M3	3.225	99.282	201.872	0.001563	2063.6
M4	2.984	100.237	200.389	0.001581	1887
M5	3.59	99.867	201.583	0.001579	2273.6
M6	3.366	99.602	201.478	0.00157	2144.2
M7	3.299	99.822	200.889	0.001572	2098.4
M8	3.62	100.18	200.722	0.001582	2288
M9	3.351	99.403	201.556	0.001564	2142.3
M10	3.438	100.748	202.894	0.001617	2125.6
M11	3.536	99.217	199.306	0.001541	2294.7
M12	3.363	100.797	200.033	0.001596	2106.9
M13	3.539	100.155	203.278	0.001601	2209.8
M14	3.731	100.194	200.122	0.001578	2364.6

Table A : Cost Analysis of Different Mix

Cost Analysis of Different Mix							
		Material Cost per cubic meter in each type of specimen (BDT)					
Mix ID	Specimen type	Cement	Sand (FA)	Stone (CA)	Wood Dust (WD)	Iron Dust (ID)	Cost per cubic meter (1 m³) of Concrete
M1	PC	15950	5297.21	8828.68	0.00	0.00	30075.88
M2	PC+WD (5%)	15950	5032.34	8828.68	0.00	0.00	29811.02
M3	PC+WD (10%)	15950	4767.48	8828.68	0.00	0.00	29546.16
M4	PC+WD (15%)	15950	4502.62	8828.68	0.00	0.00	29281.30
M5	PC+WD(5%)+ID(1%)	15950	5032.34	8828.68	0.00	0.00	29811.02
M6	PC+WD(10%)+ID(1%)	15950	4767.48	8828.68	0.00	0.00	29546.16
M7	PC+WD(15%)+ID(1%)	15950	4502.62	8828.68	0.00	0.00	29281.30
M8	PC+WD(5%)+ID(2%)	15950	5032.34	8828.68	0.00	0.00	29811.02
M9	PC+WD(10%)+ID(2%)	15950	4767.48	8828.68	0.00	0.00	29546.16
M10	PC+WD(15%)+ID(2%)	15950	4502.62	8828.68	0.00	0.00	29281.30
M11	PC+WD(5%)+ID(3%)	15950	5032.34	8828.68	0.00	0.00	29811.02
M12	PC+WD(10%)+ID(3%)	15950	4767.48	8828.68	0.00	0.00	29546.16
M13	PC+WD(15%)+ID(3%)	15950	4502.62	8828.68	0.00	0.00	29281.30
M14	PC+WD(7%)+ID(10%)	15950	4926.40	8828.68	0.00	0.00	29705.08

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Table A21: Compressive Splitting Tensile Strength of Concrete at Different Mix

Specimen ON.	Test of Specimen	M1	M2	M3	M4	M5	M6	M7	M8	M9	M10	M11	M12	M13	M14
1	Compressive stress (MPa)	21.7	12.7	7.0	5.6	13.7	7.9	6.4	19.4	8.5	6.6	23.1	10.0	6.9	25.6
2	Compressive stress (MPa)	22.1	13.6	7.5	5.8	13.4	7.8	6.1	20.1	8.8	6.4	23.5	9.8	7.0	25.5
3	Compressive stress (MPa)	21.6	13.8	7.4	5.6	13.6	7.5	6.3	19.6	8.5	6.8	23.3	10.2	7.1	25.5
4	Tensile stress (MPa)	2.23	1.24	1.23	0.70	1.91	1.23	0.94	1.93	1.14	0.96	2.37	1.28	1.22	2.36
5	Tensile stress (MPa)	2.25	1.23	1.05	0.61	1.97	1.23	1.03	2.00	1.40	1.00	2.41	1.38	1.23	2.44
6	Tensile stress (MPa)	2.24	1.22	1.14	0.51	1.23	1.22	0.99	1.96	1.27	0.98	2.39	1.33	1.22	2.40