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SCRUTINY OF ANTHRACITE WASHERY REPUDIATED BY FRAGMENTARY SUBSTITUTION OF COARSE AGGREGATE EXPLORATION OF MECHANICAL PROPERTIES

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ABSTRACT
This abstract provides a thorough examination of the use of Anthracite Washery Reject (AWR) material as a partial substitute for coarse aggregate in concrete production. It investigates the mechanical properties of resulting concrete, focusing on compressive strength, durability, and structural performance. The study aims to offer insights into incorporating AWR in concrete mixes, contributing to sustainable construction practices and efficient resource utilization in the construction industry. The investigation introduces AWR as a substitute for coarse aggregate, evaluating its mechanical properties by replacing coarse aggregate with AWR at varying levels (0% - 30%). Mechanical traits, including compressive and splitting strengths, durability indicators like water absorption, porosity, drying shrinkage, and Rapid Chloride Permeability Test (RCPT), were examined for 30% AWR replacement across different curing ages, comparing results against M 25 grade conventional concrete (CC).The findings indicate that higher AWR replacement levels led to a decline in strength properties, notably significant beyond the 30% replacement threshold. The study recommends a 30% AWR replacement for structurally safe concrete. Additionally, the investigation explores Fly Ash (FA) as an alternative to Cement, partially replacing coarse aggregate by AWR (30%) and Cement by FA (30%) in concrete composition. Properties such as compressive strength, water absorption, Rapid Chloride Permeability Test, and drying shrinkage were evaluated at different curing periods, comparing them with M 25 grade conventional concrete. This research highlights the potential of AWR as a coarse aggregate substitute and FA as a Cement alternative in enhancing the sustainability of concrete production. It addresses challenges related to resource scarcity and waste accumulation in the construction industry, aiming to offer more eco-friendly and efficient alternatives in concrete formulation.

Keywords:
Compressive strength, splitting tensile strength, Durability indicators, Water absorption, Porosity drying shrinkage.

INTRODUCTION

General

The ongoing research focuses on improving concrete properties by incorporating industrial by-products and contemporary waste materials. Efforts are directed toward using materials like fly ash, silica fume, and glass cullet as substitutes for aggregates or cement in concrete. This exploration is driven by environmental concerns and the need for safe disposal of these by-products. There is a significant emphasis on environmental preservation and recycling waste materials, particularly from industries generating substantial residues. Studies over the last twenty years have investigated various urban waste types for use in industrial building materials. This not only offers ecological benefits but also positively influences the properties of the final construction products. Since aggregates form a large portion of concrete volume and significantly influence its properties, the diminishing supply of quality aggregates in the Indian construction industry necessitates identifying alternative sources. Extensive research has

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looked into materials like coal powder, blast furnace slag, fiberglass waste, plastics, rubber, sintered fly ash pellets, and others to substitute aggregates in concrete and mortar. This approach helps mitigate aggregate shortages on construction sites and addresses environmental concerns linked to aggregate mining and disposal. However, the choice of waste material as an aggregate requires thorough evaluation due to its substantial impact on concrete properties. Waste categorization distinguishes between industrial by-products such as coal ash, metal industry slags, and pulp/paper waste, and reusable waste like plastics and rubber.

1. Coal Washery Residues

The study introduces coal washery rejects (CWR) derived from coal washing as a potential substitute for coarse aggregate in concrete. With the goal of broadening the options for sustainable concrete production, this exploration seeks to utilize this novel waste material in the construction industry.The text details the prevalence of coal-based power generation in India and globally, emphasizing the increasing demand for coal across various sectors. It delves into the characteristics of anthracite, a type of coal, highlighting its composition, evolution, impurities, and the need for washing to meet cleaner energy demands and environmental sustainability goals. Despite challenges like high ash content and moisture, Indian anthracite is subject to washing processes to enhance its quality for industrial applications. However, this washing generates anthracite washery rejects (AWR) in large quantities, posing disposal challenges and environmental concerns. Recent initiatives suggest recycling AWR for power generation and propose its use as a substitute for coarse aggregate in concrete to address disposal issues and potentially enhance concrete properties.

2.Recycled Aggregates from Mechanical Sources

This research explores the feasibility of employing AWR as a coarse aggregate substitute in concrete, aligning with efforts to recycle industrial by-products and waste materials for sustainable construction practices. It emphasizes the broader trend in the construction industry of utilizing various waste materials as aggregate substitutes to address aggregate shortages and reduce environmental impacts associated with mining and waste disposal.

The text examines industrial waste aggregates, spanning various materials based on their chemical compositions and origins. It delineates the distinction between organic waste aggregates like plastics, rubber, and certain food industry residues, and inorganic waste aggregates such as industrial slag, mining residues, and remnants from the anthracite industry. Some materials, like glass-reinforced plastics and specific industrial sludge, exhibit a blend of both organic and inorganic components.

3.Utilizing Coal Ash for Concrete Aggregates

It further categorizes industrial waste aggregates by their weight characteristics, highlighting the lightweight properties of certain aggregates like plastics, rubber, residues from food and agricultural industries, and coal-based powders. Conversely, many industrial slags possess heavier characteristics compared to traditional aggregates. The text then explores the utilization of anthracite ash in concrete production. It discusses the waste materials generated from anthracite combustion—fly ash and bottom ash—and their distinct compositions. The properties of coal ash vary based on multiple factors, and while there's substantial literature on fly ash's use in ordinary Portland cement, information about using fly ash, coal bottom ash (ABA), and boiler slag as granular additives in concrete is limited. This scarcity is especially notable for ABA and boiler slag, prompting the need for further investigation into their properties and potential applications in concrete.

4. Solid Residual Ash

The discussion shifts to Dry Bottom Ash (ABA), influenced by factors such as combustion efficiency and extraction methods. ABA's physical properties, notably lower density compared to natural sand, suggest its potential as a lightweight aggregate for concrete. Its porous nature and higher water absorption capacity, varying between different ABAs, pose challenges in determining the water-to-cement ratio in concrete mixes. However, ABA's ability to absorb water can act as internal curing in high-strength concrete formulations, providing additional water for continuous hydration and enhancing concrete properties by filling pores or micro-cracks.

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5. Project Objectives and Focus

The research focuses on introducing Anthracite Washery Rejects (AWR) as a substitute for coarse aggregates in concrete within the construction industry. The primary objectives involve studying the mechanical and durable properties of concrete incorporating AWR. This study includes replacing varying levels of coarse aggregates with AWR (ranging from 0% to 30%).

Key parameters like Compressive Strength, Split Tensile Strength, Bond Strength, and Modulus of Elasticity (MOE), along with several durable properties such as Rapid Chloride Permeability Test (RCPT), Drying Shrinkage, Water Absorption, Porosity, Ultrasonic Pulse Velocity (UPV - a non-destructive property), and Impact Strength (a destructive property) of concrete will be meticulously assessed at different curing periods. These evaluations aim to compare the performance of concrete containing AWR against M25 grade conventional concrete (CC). The goal is to comprehensively understand the feasibility and potential of AWR as a substitute in concrete production.

II. Literature Inspection

Literature Review-Introduction

In this chapter, the focus is on research initiatives exploring the integration of diverse industrial by-products and waste materials into concrete applications. It offers an extensive overview of studies conducted by various researchers investigating the use of these materials as complete or partial substitutes for aggregates in concrete.

The discussion highlights: the rapid expansion of the construction industry alongside concerns about dwindling natural resources and environmental degradation, particularly in emerging economies. This unsustainable trajectory necessitates a shift towards utilizing industrial by-products and waste materials to achieve environmental sustainability.

Ganjian et al. (2012)

As aggregates form a substantial portion of concrete volume and significantly impact its properties, incorporating waste materials as aggregate substitutes presents an opportunity to efficiently utilize large quantities of waste. Consequently, there is growing interest in using waste materials as alternatives to traditional aggregates in concrete formulations. Researchers have actively explored various materials, including coal ash, blast furnace slag, fiberglass waste, discarded plastics, rubber waste, and sintered sludge pellets, as potential substitutes for traditional aggregates in concrete.

Manso et al. (2014)

Additionally, the text touches on boiler slag, highlighting its reputation for exceptional durability and environmental stability due to the encapsulation of chemical constituents within an amorphous, glassy structure. Boiler slag is characterized by porous, glassy, angular granular particles, which can become vesicular or porous upon quenching if gases are trapped within it. The review encompasses detailed insights into different types of industrial slag and byproducts used as potential aggregates in concrete production. It starts by discussing boiler slag derived from lignite or sub-bituminous coal combustion, noting its varied porosity based on coal types. The composition, particle size distribution, and key chemical constituents of boiler slag are outlined, highlighting its SiO_2, Al_2O_3, Fe_2O_3, CaO, MgO, and TiO_2 content.

Pacheco-Torgal and Jalali (2018)

The minerals present, specific gravity, dry unit weight, and the necessity of removing deleterious materials before utilizing boiler slag as an aggregate are emphasized. Moving on to industrial slag, it delineates ferrous slag and steel slag. Ferrous slag originates from iron production in blast furnaces or steelmaking, while steel slag arises from steelmaking processes like the electric arc furnace or basic oxygen furnace. Various types of steel slag are discussed, highlighting their formation and the complex matrix of silicates and oxides they create. Additionally, it touches upon the potential utilization of steel mill scale in concrete production, similar to steel slag .The text also addresses the mineralogical complexity of fly ash, distinguishing between low calcium and high calcium fly ash and their respective compositions. High calcium fly ash's limitations due to undesirable chemical components are

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mentioned. The literature review extensively covers the utilization of steel slag as an aggregate in cement and concrete applications, drawing on various studies and findings in the field.

Guney et al. (2020)

It highlights the scarcity of reports on the use of steel slag as aggregate in cement mortar and concrete preparation, contrasting the references available for BOF-slag and EAF-slag. While BOF-slag is utilized as aggregate in concrete, more references are accessible on EAF-slag, which is primarily used as a mineral admixture in cement due to its particle size and mineralogy. The text details the physical characteristics of steel slag aggregates, emphasizing their hard, dense, angular, and often cubical particle shapes. It notes the interlocking properties of steel slag aggregates, mentioning their lower Flakiness Index compared to dolerite and quartzite aggregates. Additionally, the lower amount of earth bump and friable material in steel slag compared to typical aggregates is highlighted.

Suzuki et al. (2021)

Studies evaluating the physical properties of crushed steel slag for aggregate use reveal that steel slag meets established standards and exhibits superior characteristics such as higher abrasion resistance but lower crushing values compared to conventional aggregates. However, it mentions that steel slag has higher specific gravity, water retention capacity, and porosity compared to typical aggregates, with reported porosity levels around 10.5%.Surface analyses demonstrate a rougher composition in steel slag compared to limestone aggregates. The presence of numerous pores on the surface of EAF-slag is highlighted through electron micrographs, indicating higher mass density compared to natural aggregates.The text delves into challenges posed by the considerable presence of free lime (free-CaO) and periclase (MgO) in different types of steel slags, necessitating extensive treatment before their use in concrete. Various techniques like aging, weathering, steam, and autoclave curing are discussed to reduce the high oxide content in slag. Moreover, it briefly touches upon the utilization of bottom ash in concrete, discussing its higher porosity and void content compared to natural aggregates and its impact on concrete workability and strength properties. Overall, the review emphasizes the physical properties, challenges, and potential treatment methods required for incorporating steel slag as an aggregate in cement and concrete applications while providing insights into its performance in comparison to conventional aggregates. The literature review encompasses a diverse range of alternative aggregates utilized in concrete production, showcasing various materials and their impact on concrete properties. Studies on plastic aggregates (PA) demonstrated decreased slump in fresh concrete but highlighted its potential to impede micro crack propagation, enhancing concrete toughness. Granulated blast furnace slag (GBFS) was employed as a partial replacement for fine aggregate, while paper mill sludge and quarry rock dust were explored as substitutes for fine aggregate, each having distinct characteristics affecting water absorption and composition compared to typical aggregates. Utilization of waste materials from the ceramic industry, such as ceramic waste aggregates, crushed tile waste, and porous waste ceramic coarse aggregate, provided insights into their feasibility as concrete aggregates, considering their specific gravity, surface texture, and mineral content. Moreover, ceramic waste types, like ceramic bricks and sanitary ware, were examined as coarse aggregates, even substituting cement in concrete production, reflecting diverse possibilities for waste reuse.Studies on foundry sand and discarded tyre waste explored their potential as high-performance concrete aggregates. Foundry sand, a high-quality silica by-product, displayed advantages due to its initial high quality, while tyre rubber particles posed challenges due to their size, proportion, and surface characteristics impacting concrete strength and water demand.

III. Experimental Methodology

The section outlines the pivotal role of materials in determining concrete properties, specifically focusing on the constituents utilized for both traditional concrete (CC) and Anthracite Washery Rejects (AWR)-based concrete. It starts with the presentation of chemical and physical properties of the materials chosen for the fabrication, beginning with the use of Ordinary Portland Cement 53 grade (Penna) in compliance with IS 12269-(1987).

The text outlines a comparative presentation, likely in tabular form, indicating serial numbers alongside particulars, test results, and corresponding requirements as per the IS:12269-1987 standard. This comparison likely highlights how the test results align with the specified requirements outlined in the standard. **Table 3.1.1.a)**

S.No	Particulars	Test result	Requirement as per IS:12269-1987

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Chemical Composition			
1	% Silica(SiO_2)	**19.79**	
2	% Alumina(Al_2O_3)	**5.67**	
3	% Iron Oxide(Fe_2O_3)	**4.68**	
4	% Lime(CaO)	**61.81**	
5	% Magnesia(MgO)	**0.84**	Not more Than 6.0%
6	% Sulphuric Anhydride (SO_3)	**2.48**	Max. 3.0% when $C_3A>5.0$ Max. 2.5% when $C_3A<5.0$
7	% Chloride content	**0.003**	Max. 0.1%
8	Lime Saturation Factor $CaO-0.7SO_3/2.8SiO_2+1.2Al_2O_3+0.65Fe_2O_3$	**0.92**	0.80 to 1.02
9	Ratio of Alumina/Iron Oxide	**1.21**	Min. 0.66

The Physical Properties

This text refers to a table, likely labeled as Table 3.1.2, which summarizes the physical properties and the results of different tests performed on cement, following the standards outlined in IS 4031(1988). The table presumably provides a concise overview of these physical properties and test outcomes.

Table 3.1.1.b) Physical Properties of Cement

S.No	Physical properties	Test result	Test method/ Remarks	Requirement as per IS 12269 (1987)
1	**Specific gravity**	3.15	IS 4031(1988) – part 11	-
2	**Fineness (m^2/Kg)**	311.5	Manufacturer data	Min.225 m^2/kg
3	**Normal consistency**	30%	IS 4031 (1988)- part 4	-
4	**Initial setting time (min)**	90	IS 4031 (1988)- part 5	Min. 30 min
5	**Final setting time (min)**	220	IS 4031 (1988)- part 5	Max. 600 min
6	**Soundness** **Lechatelier Expansion (mm)** **Autoclave Expansion (%)**	0.8 0.01	Manufacturer data	Max. 10 mm Max. 0.8%
7	**Compressive strength (MPa)** **3 days** **7 days** **28 days**	25 39 57	IS 4031 (1988)- part 6	27 MPa 37 MPa 53 MPa

Sieve analysis

This section details the specifications of the coarse aggregate used, sourced from crushed granite stones available in two sizes, 20 mm and 10 mm. It outlines their mass-specific gravity, water retention values, mass density, impact strength, and crushing strength, all measured in accordance with IS 2386 (Part III, 1963). Additionally, it discusses the gradation analysis conducted following IS 383 (1970), presenting the results in Tables 3.1.2.1 and 3.1.2.2, along with the grading curves illustrated in Graphs: Graph 3.1.2.1 and Graph 3.1.2.2.

Table 3.1.2.1. Sieve analysis of 20 mm Coarse Aggregate

S.No	Sieve size	Cumulative percent passing	
		20 mm	**IS 383 (1970) limits**
1	20 mm	100	85-100

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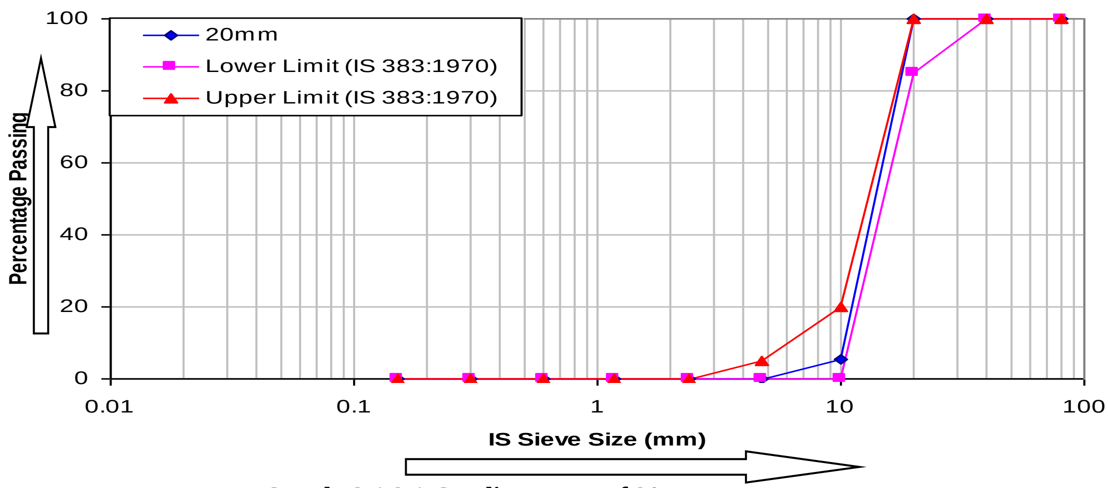
2	16 mm	56.17	N/A
3	12.5 mm	22.32	N/A
4	10 mm	5.29	0-20
5	4.75 mm	0	0-5

Table 3.1.2.2. Sieve analysis of 10 mm coarse aggregate

S.No	Sieve size	Cumulative percent passing	
		10 mm	IS 383 (1970) limits
1	10 mm	99.68	85-100
2	4.75 mm	8.76	0-20
3	2.36 mm	2.4	0-5



Graph. 3.1.2.1 Grading curve of 20 mm coarse aggregate

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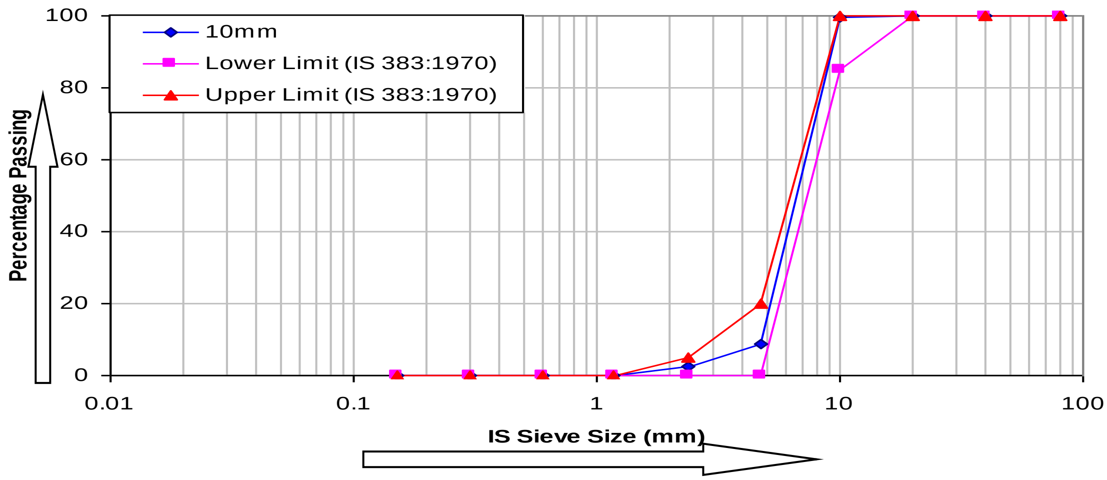

Graph. 3.1.2.2 Grading curve of 10 mm Coarse Aggregate.

This section describes the fine aggregate utilized, sourced from natural river sand, outlining its bulk specific gravity and water absorption measurements in compliance with IS 2386 (Part III, 1963). It discusses the sand's gradation obtained through sieve analysis according to IS 383 (1970), presented in Table 3.5, and the grading curve depicted in Fig. 3.3 as outlined by IS 383 (1970). Additionally, it notes the sand's fineness modulus recorded as 2.26.

Table 3.1.3. Sieve analysis of Fine Aggregate

S.No	Sieve No.	Cumulative percent passing	
		Fine aggregate	IS: 383-1970 – Zone III requirement
1	3/8” (10mm)	100	100
2	No.4 (4.75mm)	100	90-100
3	No.8 (2.36mm)	100	85-100
4	No.16 (1.18mm)	99.25	75-100
5	No.30 (600µm)	65.08	60-79
6	No.50 (300µm)	7.4	12-40
7	No.100 (150µm)	1.9	0-10

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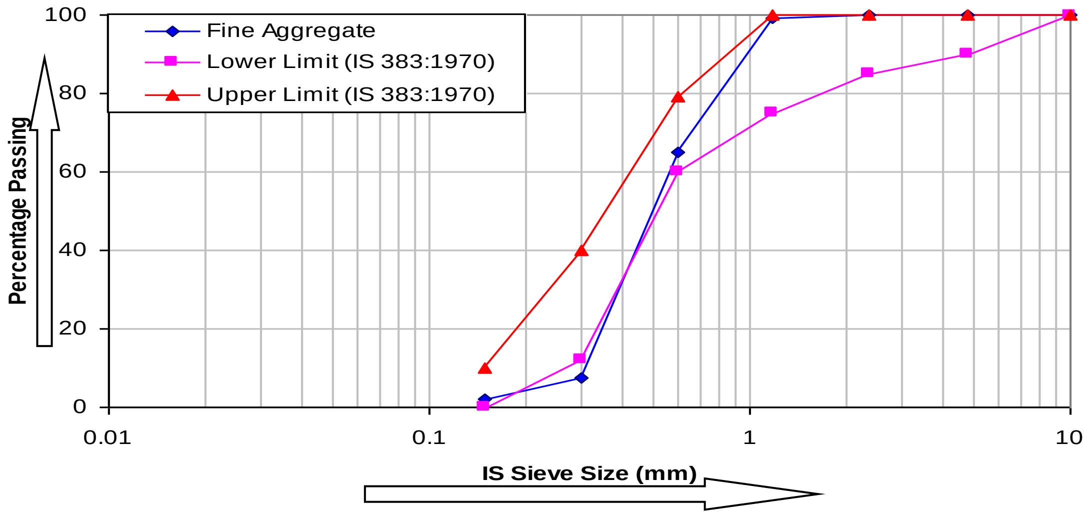

Graph. 3.1.3. Grading curve of fine aggregate

Mix proportions of constituent materials of concrete mixes

This section describes the mix design approach used in creating the concrete blend. It incorporates both 20 mm and 10 mm coarse aggregate particles in a 60:40 ratio by weight, ensuring sufficient reinforcement bonding in building structures. Within this mix, 30% of the 20 mm coarse aggregate was systematically substituted with 20 mm AWR. The design adheres to the specifications outlined in IS 10262:2009 and IS 456:2000 for the M 25 grade of conventional concrete (CC). The specific proportions of constituent materials are provided in detail in Table 3.7.1.

Table 3.7.1: Mix proportions of constituent materials of concrete mixes

S.No	Mix type	Cement kg/m^3	FA Kg/m^3	Water l/m^3	CA 20 mm kg/m^3	10 mm kg/m^3	AWR 20 mm kg/m^3	Sand kg/m^3
1	(M 25)	384	0	192	683	456	0	636
2	FA_20	267	81	192	546	456	137	636

Procedure

The 100mm dia x 50 mm height cylinder after casting were immersed in water for 90 days curing These specimens were then oven dried for 24 hours at the temperature110°C until the mass became constant and again weighed. This weight was noted as the dry weight (W1) of the cylinder .After that the specimen was kept in hot water at 85°c for 3.5 hours. Then this weight was noted as the wet weight (W2) of the cylinder.

% water absorption = [(W2– W1) / W1] x 100

Where,

W1 = Oven dry weight of cylinder in grams

W2 = After 3.5 hours wet weight of cylinder in grams.

3.6.2. Drying shrinkage

Loss of water from the solidified solid causes drying shrinkage. Drying shrinkage of Solidified concrete was measured according to ASTM C 157-03. Three samples were utilized for this test. The length of crystal was recorded as starting comparator perusing after beginning water-curing time of 28 days and examples were put away in the drying room. The comparator readings were taken after time of air stockpiling in the wake of curing of 28,56 and 90 days and after 8, 16, and 32 weeks. The length change at any age after initial reading calculated as follows

ΔLx = (CRD – Initial reading)/G x 100

Where ΔLx = length change of specimen at any age,

(%) CRD = difference between the comparator reading of the specimen and reference bar at any age

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G = the gauge length (250 mm).

IV. Results and Discussion

This chapter outlines the findings from a comprehensive test series performed on concrete, specifically focusing on concrete compositions incorporating Anthracite Washery Rejects (AWR). The AWR was used as a partial replacement for coarse aggregates, with levels set at 0% and 30%. The evaluation encompassed a range of strength properties—compressive strength, split tensile strength, bond strength, Modulus of Elasticity (MOE)—and durable attributes such as Rapid Chloride Permeability (RCPT), water absorption, porosity, and drying shrinkage. These assessments were conducted over curing periods spanning 28, 56, and 90 days.

Table 4.1.1. -6 slump cone test results

S.No	Mix	Slump in mm
1	M1	68
2	M2	74
3	M3	76
4	M4	85
5	M5	91
6	M6	102

Table 4.1.2. Compaction factor test

S.No	Mix	Compaction factor
1	M1	0.92
2	M2	0.95
3	M3	0.92
4	M4	0.92
5	M5	0.92
6	M6	0.92

This segment delves into the mechanical aspects, particularly focusing on the compressive strength of two concrete types: the traditional one (CC - AWR_0) and concrete blends incorporating Anthracite washery rejects (AWR) across different curing periods.

Table 4.2.1 Compressive strength of concrete

S.No	Mix Type	Compressive Strength(M.Pa)		
		28 days	56 days	90 days
1	AWR-0	34.12	36.02	38.72
2	AWR-10	33.41	35.89	38.69
3	AWR-20	33.07	35.87	38.65
4	AWR-30	32.98	35.86	38.64

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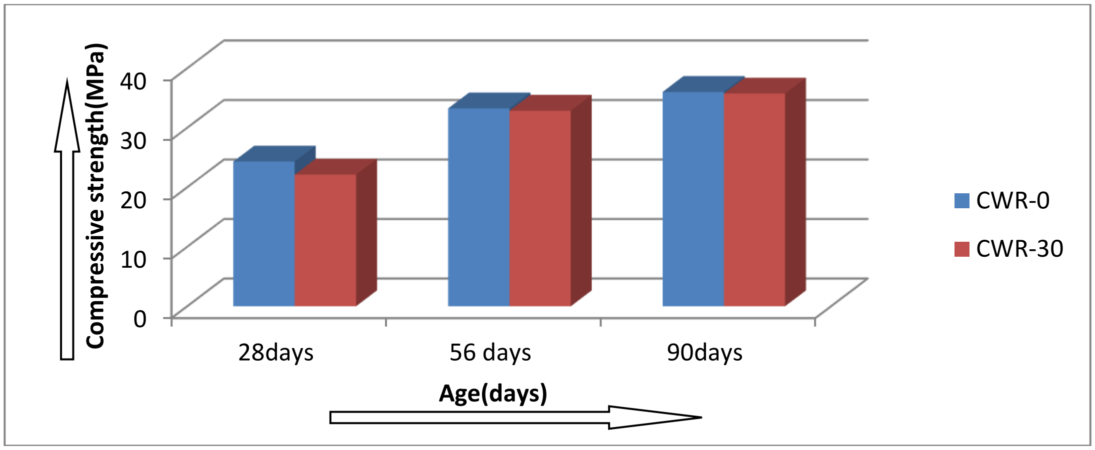
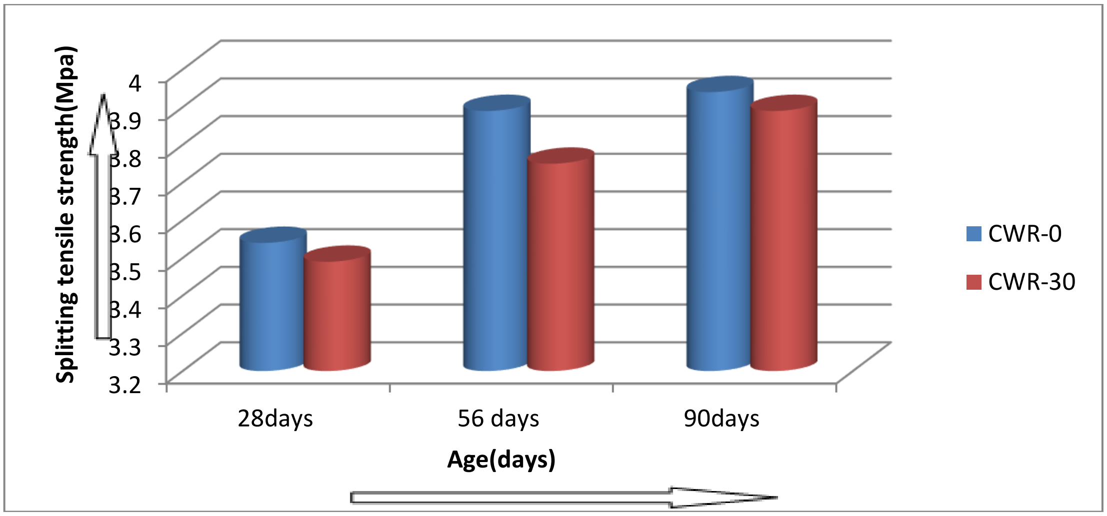


Graph 4.2.1: Compressive strength of concrete

This section scrutinizes the splitting tensile strength displayed by concrete compositions utilizing Anthracite washery rejects (AWR) as a foundational component.

Table 4.2.2. Splitting tensile strength of concrete

S.No	Mix Type	Split Tenile Strength(M.Pa)		
		28days	**56 days**	**90days**
1	**AWR-0**	3.54	3.89	3.94
2	**AWR-30**	3.49	3.75	3.89



Graph 4.2.2: Splitting tensile strength of concrete

4.2.4 Modulus of elasticity (MOE)

This chapter focuses on exploring the Modulus of Elasticity (MOE) of concrete across various curing durations, examining its behavior and characteristics over time.

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Table No.4.4 Modulus of elasticity

S.No	Mix Type	Modulus of elasticity (G.Pa) at curing age (days)		
		28 days	**56 days**	**90 days**
1	**AWR-0**	29.18	29.56	29.82
2	**AWR-30**	27.32	28.19	29.71

The conclusive findings from the investigation into Anthracite washery rejects (AWR) as partial replacements for coarse aggregate in concrete are summarized in this final chapter:

- Concrete mixes incorporating AWR as a partial replacement consistently demonstrate lower values in compressive, splitting tensile, bond strength, and MOE properties across all ages compared to conventional concrete.
- The reduction in crushing and impact strength of AWR is linked to decreased compressive, splitting tensile, bond, and MOE properties within these concrete mixes.
- Concrete mixes AWR_20 and AWR_30 exhibit comparable 28-day compressive strength to that of M 25 grade conventional concrete (CC), although higher replacement percentages, particularly AWR_40 and AWR_50, show a notable decrease in strength properties.
- Incorporating AWR at a 30% partial replacement of coarse aggregate could achieve desired conventional concrete values based on the study's results.
- The investigation into durable properties indicates moderate RCPT values and consistently lower water absorption values across all curing periods compared to conventional concrete. AWR-based concrete exhibits slightly higher porosity values but lower drying shrinkage compared to conventional concrete.

Conclusions

These conclusions offer insights into the performance and characteristics of concrete mixes containing Anthracite washery rejects, shedding light on their potential use and the variations in properties when utilized as a partial replacement for coarse aggregate.

The future work section highlights potential areas for further investigation based on this project's findings:

A thorough exploration of the durability properties in concrete mixes using Anthracite washery rejects (AWR).

Considering the ecological implications and resource availability, an examination of substituting a portion of sand with bottom ash in AWR-based concrete mixes to assess their overall hardened and durability properties.

An in-depth analysis of the micro-level properties inherent in concrete mixes utilizing AWR.

Moreover, this chapter encompasses the overarching conclusions drawn from the examination of concrete that incorporates Fly ash as a partial replacement for cement and AWR as a substitute for coarse aggregate.

Actual quantities of mix proportions

The duly adjusted actual quantities of mix proportions are described below. In the mix, 20 mm and 10 mm coarse aggregates are blended in 60:40 proportion by percentage weight of total aggregate. Mix proportion of cement, fine aggregate and coarse aggregate by weight is given by 1 :1.66 : 2.97.

Cement : 384 kg/m^3
Water : 202 kg/m^3
Coarse aggregate : 1139 kg/m^3
20 mm : 683.4 kg/m^3
10 mm : 455.6 kg/m^3
Fine aggregate : 636 kg/m^3

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