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Performance Evaluation of Self-Curing, Self-Compacting Concrete Incorporating Sintered Fly Ash Lightweight Aggregate as a Partial Replacement for Coarse Aggregate

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Abstract: With technological advancements, concrete has undergone various modifications while retaining its strong mechanical properties. As the second most consumed material after water, it is widely used due to its high compressive strength. Self-Compacting Concrete (SCC) flows under its own weight without the need for vibration, enhancing workability and reducing labor, cost, and casting difficulties. Its key parameters are filling ability, passing ability, and resistance to segregation. Curing ensures proper hydration, and self-curing helps retain internal moisture. Combining both, Self-Compacting Self-Curing Concrete (SCSCC) is developed using mineral admixtures and curing agents. Sintered Fly Ash Lightweight Aggregate replaces coarse aggregate, reducing the concrete's dead weight and promoting sustainability.

This study investigates the development of Self-Curing Self-Compacting Concrete (SCSCC) using Sintered Fly Ash Lightweight Aggregate (SFA-LWA) as a partial replacement for coarse aggregate at 10%, 20%, 30%, and 40% by weight. A super plasticizer (STRUCTURO-203) at 0.6% and a self-curing agent (Polyethylene Glycol 600) at 0.5% by weight of binder were used. Fresh properties were evaluated using Slump Flow, T50, V-Funnel, L-Box, and U-Box tests. Hardened properties—compressive, split tensile and flexural strengths—were assessed using cube, cylinder, and prism specimens. While compressive and tensile strengths decreased with higher SFA replacement, flexural strength improved. Curing was done conventionally for control mixes and under ambient conditions for self-curing mixes. The study was carried out through material testing, specimen casting, and performance comparison.

Index Terms **- Self-Compacting Concrete, Self-Curing Self-Compacting Concrete, Compressive Strength, Split Tensile Strength and Flexural Strength**

I. INTRODUCTION

Civil engineering is a foundational profession, critical to both developed and developing nations. With their technical expertise and creative problem-solving abilities, civil engineers plan, design, construct, maintain, and manage the infrastructure systems essential to modern life. These include everything from highways, bridges, and railways to water supply networks, waste management systems, buildings, and dams.

Civil engineering is a broad and interdisciplinary domain that includes major branches like structural, geotechnical, transportation, water resources, and environmental engineering. With rising global populations and growing environmental concerns, the demand for civil engineers is increasing across the globe. These professionals play a crucial role in addressing challenges like urban development, pollution control, sustainable energy, efficient transportation, and infrastructure resilience. Civil engineering offers a broad spectrum of career opportunities, including roles in design, construction, research, education, project management, and policy planning. Buildings, bridges, and other load-bearing structures are planned, designed, and

evaluated by structural engineers, a significant subfield of civil engineering. This involves calculating forces and stresses within structures to ensure they can withstand loads from wind, seismic activity, and other environmental factors. Structural engineers also work on retrofitting existing buildings to improve performance during earthquakes or extreme weather events. Demolition wastes, construction waste (DWC) and industrial waste materials are utilized in concrete. Abatement in workability with rise in recycled coarse aggregate had managed to avoid with the help of chemical admixtures and by using SSD aggregates.

1.1 SELF COMPACTING CONCRETE

In Japan, worries regarding the longevity of concrete constructions were prominent starting in 1983. Historically, careful compaction by knowledgeable workers was necessary to achieve long-lasting concrete construction. However, when competent labor became increasingly scarce in Japan's building industry, the quality of construction started to deteriorate. Self-compacting concrete (SCC) was developed as a remedy for this problem. This kind of concrete doesn't require mechanical vibration because it can flow and fill formwork entirely under its own weight. Okamura suggested the necessity of such a concrete in 1986. SCC was later developed as a result of groundbreaking research on concrete workability carried out by researchers Ozawa and Maekawa at the University of Tokyo.

1.2 SELF CURING CONCRETE

The process of self-curing, sometimes referred to as internal curing, involves adding more moisture to concrete in order to improve cement hydration and lessen self-desiccation. This method boosts overall durability, decreases the chance of autogenous shrinkage and cracking, improves hydration and strength gain, and decreases permeability. Internal curing was created to solve problems with high-strength and high-performance concrete (HSC/HPC), including shrinkage and self-desiccation, which are sometimes thought of as the concrete's main shortcomings. The continuing of cement hydration using internal water sources that were not included in the initial mixing water is known as internal curing, according to the American Concrete Institute (ACI). The pore structure of pre-wetted lightweight aggregates, which serve as internal reservoirs, is usually used to accomplish this. When necessary, these aggregates release water gradually, either to maintain continuous hydration or to restore moisture lost to evaporation or self-desiccation.

1.3 SINTERED FLY ASH (SFA)

Fly ash, a byproduct of burning coal in thermal power plants, is sinterable at high temperatures to create sintered fly ash (SFA), a sort of artificial lightweight aggregate. Fine fly ash particles are changed by this procedure into hard, lightweight, porous granules that can be used in construction and concrete. SFA aggregates are a sustainable substitute for natural aggregates due to their low density, high strength-to-weight ratio, and strong insulating qualities. Their application in concrete improves durability and thermal efficiency while also lowering the dead load of buildings. Additionally, using fly ash in aggregate manufacturing helps to address environmental issues associated with the disposal of industrial waste and promotes sustainable building methods. SFA is very useful in the creation of lightweight concrete for precast elements, bridges, and tall buildings. The purpose of this study is to examine the durability, mechanical, and physical characteristics of sintered fly ash aggregates as well as how they affect the functionality of lightweight concrete systems.

1.4 SUPERPLASTICIZER STRUCTURO-203

Structuro-203 is a high-performance, third-generation super plasticizer based on polycarboxylate ether (PCE) technology, designed to significantly enhance the workability and strength of concrete. It enables a high degree of water reduction without

compromising the flow ability, making it ideal for producing self-compacting, high-strength, and durable concrete mixes. Structuro-203 improves cement particle dispersion, leading to better hydration and enhanced mechanical properties. It is particularly useful in ready-mix concrete, precast elements, and high-performance concrete applications. This research focuses on evaluating the effects of Structuro-203 on the rheological behavior, setting time, compressive strength, and durability of concrete under varying conditions.

II. METHODOLOGY

As part of the current research project, a comprehensive experimental program was conducted and methodically broken down into discrete phases. Portland Cement (PC), natural fine aggregate (NFA), natural coarse aggregate (NCA), fly ash, sintered fly ash lightweight aggregate (SFA), super plasticizer (Structuro-203), and Polyethylene Glycol 600 (PEG 600) as a self-curing agent were among the constituent materials that were chosen and characterized in the first phase. In compliance with pertinent Indian Standards (IS), laboratory tests were conducted on materials obtained from various sources to assess their mechanical and physical characteristics.

The IS: 10262-2019 requirements were followed in the creation of the concrete mix, which was intended for M30 grade concrete. Using a mix proportion of 1:1.31:2.94, standard concrete mixes were made with a water-binder ratio of 0.45.

Self-Compacting Concrete (SCC) and Self-Curing Self-Compacting Concrete (SCSCC) mix designs were created in the second phase. A water-binder ratio of 0.50 and a 1:1.90:1.92 combinations were found to be the best for SCSCC.

Standard specimens (cubes, cylinders, and prisms) were then cast and allowed to cure in order to be tested. In order to evaluate the performance of the specified concrete mixes, the experimental program ended with an assessment of essential mechanical parameters, such as split tensile strength, flexural strength, and compressive strength.

2.1 MATERIALS PROPERTIES

The materials which are used in this project are cement, fly ash, natural coarse aggregate, natural fine aggregate, sintered fly ash as light weight coarse aggregate, STRUCTURO-203 as super plasticizer and POLYETHYLENE GLYCOL 600(PEG 600). The properties of the above material are described below.

Table 4.1 Physical requirements of cement

Experiment of the Cement	Results
Fineness Kg/m^2	300
Soundness mm	1
Specific Gravity	3.15
Standard Consistency %	27.1

Table 2.2 Physical properties of Natural fine aggregate

Experiment of the Natural Sand	Result
Specific gravity of the fine aggregate	2.62
Water absorption of fine aggregate	0.7
Fineness modulus	1.6

Table 2.3 Physical properties of natural coarse aggregate

Characteristics	Result
Specific gravity	2.8
Abrasion value (%)	20.5
Impact value (%)	15.7
Water absorption (%)	0.31

Table 2.4 Properties of sintered fly ash

Properties	Values
Specific gravity	2.00
Water absorption (%)	14.25
Fineness modulus	6.3

*Table 2.5 Properties of structure-203**

Properties	Values
Relative density	1.08
pH	6.3
Dry material content	36.3
Specific gravity	1.08

4.3 MIX DESIGN

The technique known as mix design must be used to choose the mix components and the necessary material proportions before any concrete is mixed. M30 grade concrete was designed in accordance with IS code-1062-2019. This project involved designing normal vibrated concrete (NVC) of M30 grade, SCC of M30 grade according to EFNARC specifications, and SCSCC of M30 grade using various trial mix techniques that included mineral admixtures, super plasticizer, and self-curing agent. SCSCC was created by replacing coarse aggregate by sintered fly ash aggregate at 10%, 20%, 30% and 40% respectively by using dosage of super plasticizer at 0.60% and PEG600 at 0.5 by weight of binder. On new SCC properties, the slump flow, V-funnel, L-box, and U-box tests were conducted. Tests were conducted on NC, SCC, and SCSCC's compressive, split tensile, and flexural strengths. The water binder ratio for SCC MIX was set at 0.50.

Table 2.6: Initial data for mix design for M30 grade concrete

Grade of concrete	Cement material per m3 of concrete (kg/m3)	NFA	NCA	Water
M30	438	573.78	1287.72	198

Table 2.7: Percentage of aggregate used

Mix designation	Normal aggregate%	SFA(%)
Mix 0	100	0
MSCSCCSFA10	90	10
MSCSCCSFA20	80	20
MSCSCCSFA30	70	30
MSCSCCSFA40	60	40

III. Results and Discussions

3.1 Compressive strength of SCSCC

Table 3.1 Summary of Compressive Strength Test Results

Mix Identification	7 Days		28 Days	
	Compressive strength(MPa)	% change in strength w.r.t MNC	Compressive Strength (MPa)	% change in strength w.r.t MNC
MNC	33.485	0	44.06	0
MSCSCCSFA10	39.15	16.91	50.19	13.91
MSCSCCSFA20	36.15	7.9	47.56	7.9
MSCSCCSFA30	34.45	2.8	45.32	2.9
MSCSCCSFA40	31.18	-6.8	41.02	-6.8

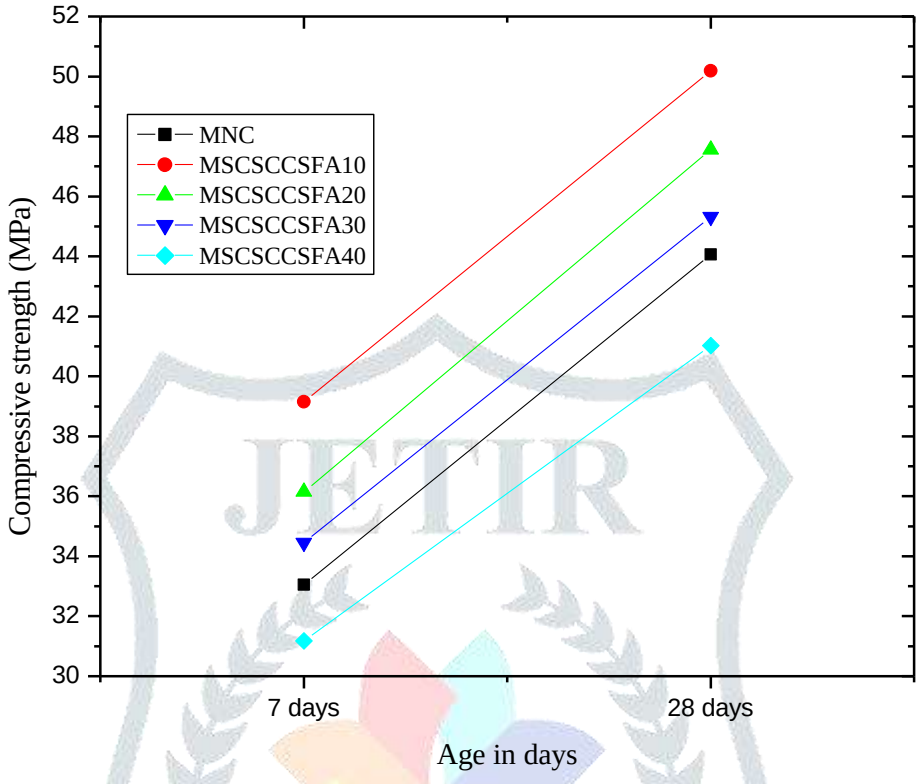


Figure3.1.1: Compressive strength verses age in days of Normal concrete and SCSCC with partial replacement of sintered fly ash

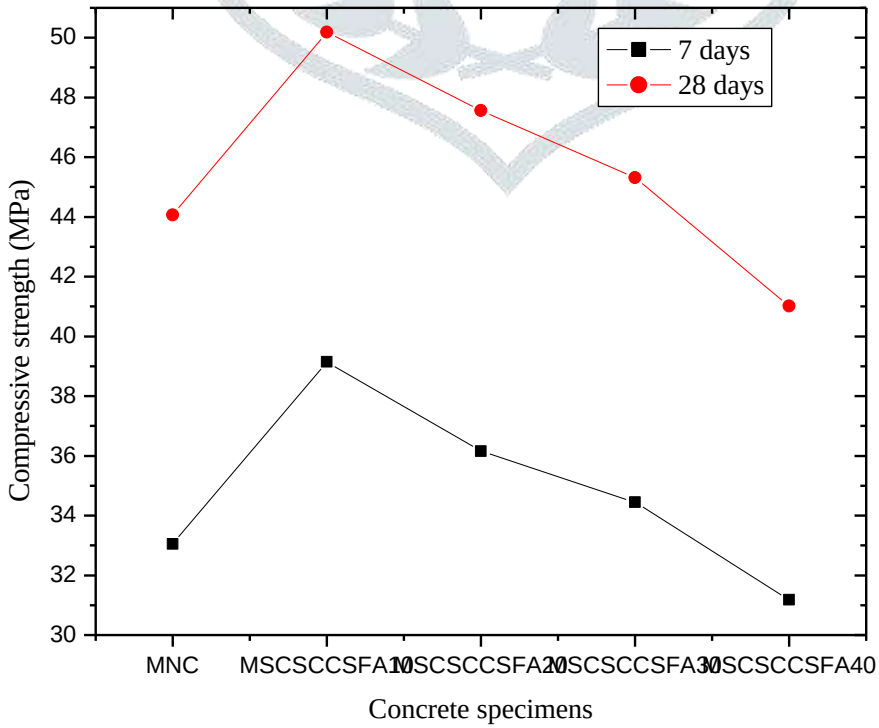


Figure3.1.2: Compressive strength verses concrete specimens of Normal concrete and SCSCC with partial replacement of sintered fly ash

From the above figures it is observed that the compressive strength of SCSCC with partial replacement of sintered fly ash aggregate at 10%, 20%, and 30% is more than that of normal concrete but the strength of SCSCC with sintered fly ash at 40% is less than that of normal concrete.

3.2 Split Tensile Strength of SCSCC

Table 3.2: Summary of split tensile strength test results

Mix Identification	7 Days		28 Days	
	Split tensile strength(MPa)	% change in strength w.r.t MNC	Split tensile Strength (MPa)	% change in strength w.r.t MNC
MNC	3.5	0	4.01	0
MSCSCCSFA10	*3.745*	*7*	*4.50*	12.21
MSCSCCSFA20	*2.818*	*-19.4*	*3.65*	-8.9
MSCSCCSFA30	*2.468*	*-29.4*	*3.11*	-22.44
MSCSCCSFA40	*2.315*	*-33.85*	*2.93*	-26.93

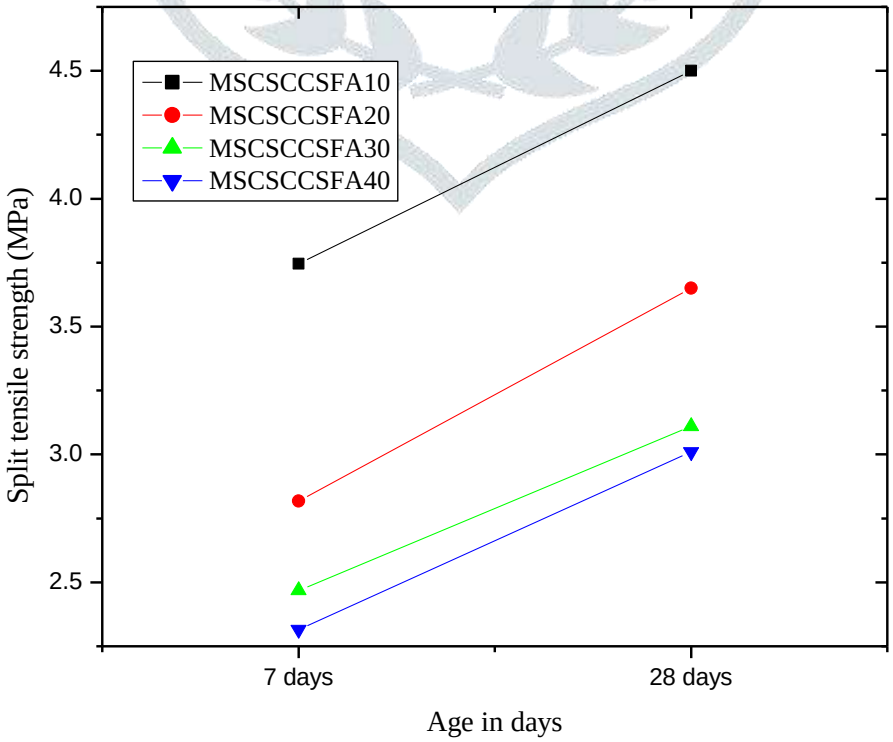


Figure 3.2.1: Split tensile strength verses age in days for SCSCC with replacement of sintered fly ash

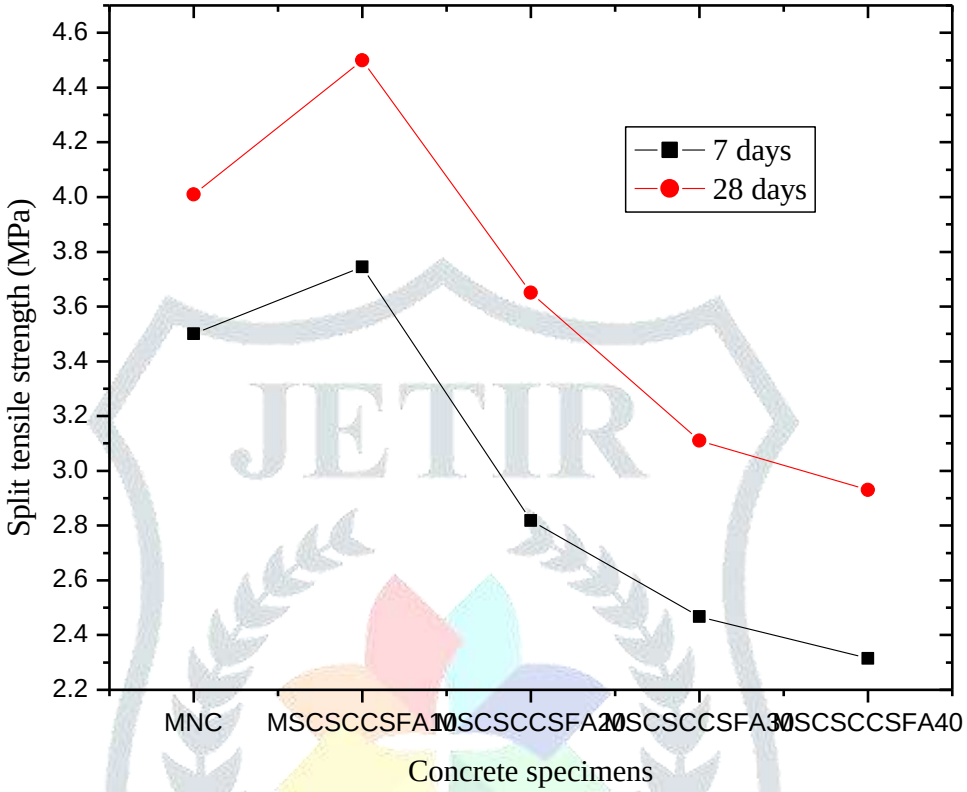


Figure 3.2.2: Split tensile strength verses concrete specimens of Normal concrete and SCSCC with partial replacement of sintered fly ash

From the above figures it is observed that the split tensile strength of SCSCC with partial replacement of sintered fly ash aggregate at 10% is more than that of normal concrete but the strength of SCSCC with sintered fly ash at 20%,30%,40% is less than that of normal concrete.

3.3 Flexural Strength of SCSCC

Table 3.3: Summary of flexural strength test results

Mix Identification	7 Days		28 Days	
	Flexursl strength(MPa)	% change in strength w.r.t MNC	Flexural Strength (MPa)	% change in strength w.r.t MNC
MNC	3.44	0	4.3	0
MSCSCCSFA10	*2.4*	*-30.28*	*3.2*	-25.58
MSCSCCSFA20	*2.8*	*-18.60*	*3.73*	-13.25
MSCSCCSFA30	*3.2*	*-6.9*	*4.13*	-3.9
MSCSCCSFA40	*3.5*	*1.7*	*4.48*	4.1

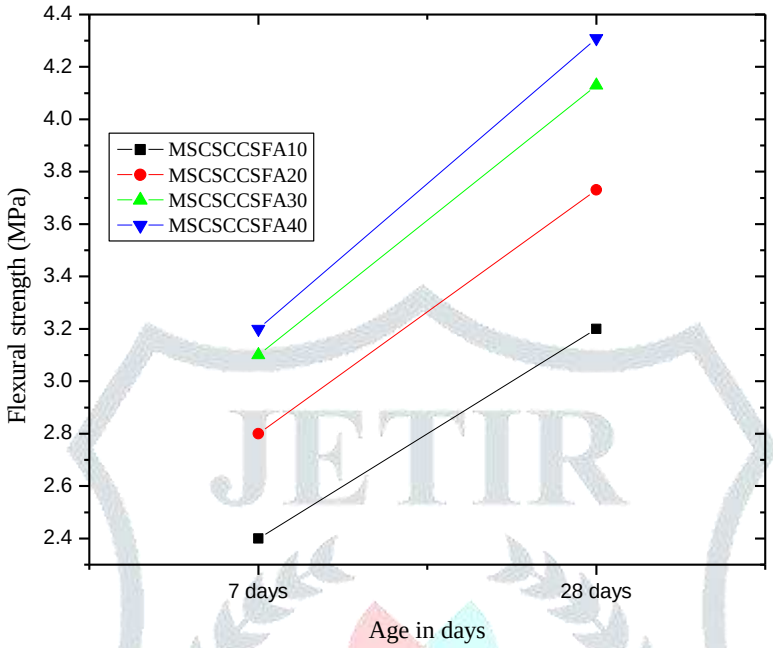


Figure.3.3.1 Flexural strength verses age in days of SCSCC with replacement of sintered fly ash

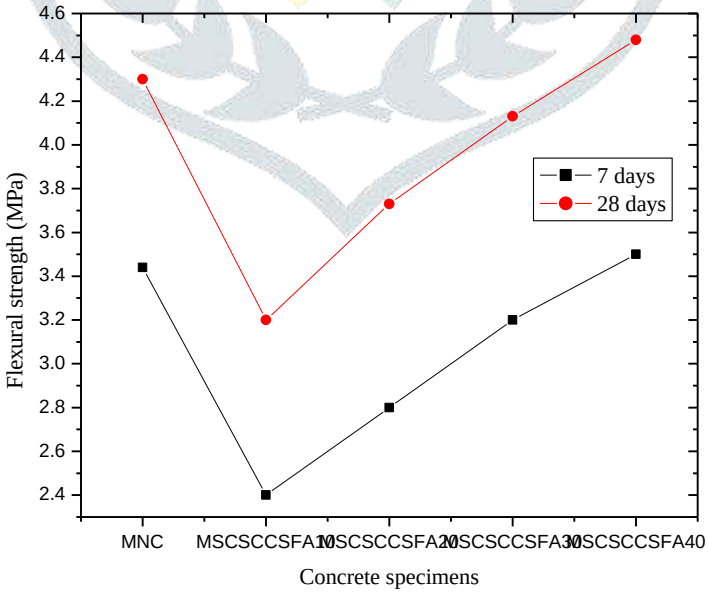


Figure.3.3.2Flexural strength verses concrete specimens of Normal concrete and SCSCC with sintered fly ash replacements

From the above figures it is observed that the flexural strength of SCSCC with partial replacement of sintered fly ash aggregate at 40% is more than that of normal concrete but the strength of SCSCC with sintered fly ash at 10%,20%,30% is less than that of normal concrete.

IV. Conclusion

1. The value of the compressive strength decreases as the percentage content of sintered fly ash increases.
2. The percentage change in compressive strength of SCSCC with partial replacement of sintered fly ash at 10%,20%,30%,40% w.r.t the strength of normal concrete is 13.91, 7.9, 2.9, -6.8 respectively.
3. The value of split tensile strength decreases as the percentage content of sintered fly ash increases.
4. The percentage change in split tensile strength of SCSCC with partial replacement of sintered fly ash at 10%, 20%, 30%, 40% w.r.t to the strength of normal concrete is 12.21, -8.91, -22.44, -26.93 respectively.
5. The flexural strength increases as the percentage content of sintered fly ash increases in concrete.
6. The percentage change in flexural strength of SCSCC with partial replacement of sintered fly ash at 10%,20%,30%,40% w.r.t to the strength of normal concrete is -25.58,-13.25,-3.9,4.1 respectively

IV. Acknowledgment

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