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Studies on the Utilization of Industrial By-Products in Self-Compacting Concrete: A Review

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Abstract— **Self-compacting concrete is being widely used across the globe because of its sublime fresh and hardened properties. With speedy industrialization and growth in construction activities, the demand for natural river sand increased drastically leading to its enormous depletion. Furthermore, the disposal of industrial waste into the land causes environmental imbalance. Based on these reasons, the approach for sustainable construction is on the rise. Hence, in order to protect the environment and promote sustainable eco-friendly development, researchers have conducted experimental investigation on the suitability of alternative fines as replacement of river sand. This paper puts forward a thorough review of the physical and chemical characteristics of industrial by-products, followed by their effect on the fresh and hardened properties of SCC. Studies reveal that there is an encouraging future for the use of alternative fines in SCC. The key objective of this paper is to assess the work done by past researchers on the incorporation of alternative fines in SCC, provide sizeable information and the portion of work that needs to be done for future research**

Index Terms— **Alternative fines, industrial by-products, self-compacting concrete, sustainable construction, filling ability, passing ability**

I. INTRODUCTION

Self-compacting concrete has been epitomized as the most indispensable advancement in concrete construction. Despite the fact that it was primitively developed to counteract the increasing shortfall of skilled labour and overcome improper compaction, SCC has proven to be profitable because of numerous factors which encompass excellent fluidity and segregation resistance, enhanced durability, faster construction, greater freedom in design, less manpower, superior surface finishes, easier placing, no need of vibration, economical etc. [1, 2]. SCC was first evolved in Japan in 1986 and its property to flow and self-consolidate was achievable only because of the early invention of super plasticizers [3, 4]. Aggregates contribute roughly to around 60-70% of the overall volume in SCC. The fresh and hardened properties of self-compacting concrete depend mainly on the aggregates and hence picking the right type of aggregate is important. The repercussions of shape and texture of fine aggregate are more decisive than of coarse aggregate [5]. Poor gradation of aggregates is also one of the agencies that can impinge the flowability of SCC. With the use of fillers, both inert and reactive, this problem may be solved [6].

The accelerated growth of construction over the past few decades has caused an enormous expenditure of naturally occurring materials for concrete production [7]. Due to this, the availability and accessibility of these natural materials is getting restricted day by day. The natural sand contributes to around 35% of the concrete volume which plays a vital role in governing the cost of self-consolidating concrete [8]. In addition, withdrawal of natural sand has serious environmental consequences and hence it is the need of the hour to scale down their utilization and look out for some alternative sources. River sand is being used in SCC for a long time. With the rise in demand and evacuation of river sand, limitations are now imposed on the exploitation of river beds. This has resulted in the search of other suitable alternatives. Alternative to river sand is being used as a filler to produce SCC, yet enough research has not been carried out on the effects of alternative fine on SCC till date [6]. These alternative fine aggregates can either be used as partial or complete replacement of river sand that will not only lower the cost but will also led to the development of eco-friendly SCC [7]. The main focus of this paper is to encapsulate the prevailing research on substituting natural river sand with industrial by-products in self-compacting concrete and their effect on the fresh and hardened properties.

II. ALTERNATIVE FINE AGGREGATES

The utilisation of alternative fine aggregates has two-fold benefits, i.e. conservation of natural materials and reduction of other environmental problems. The different types of alternative fine aggregates are as follows: A: Crushed Rock Sand (CRS)- diorite, basalt, sandstone, limestone, granite, feldspathic quartzite, metamorphic siltstone. B: Recycled Fine Aggregates (RFA) - recycled concrete, recycled bricks, recycled glass, crushed bitumen and crushed asphalt. C: Industrial By-products-Copper slag (CS), steel slag, iron slag, coal bottom ash (CBA), GGBS, waste foundry sand (WFS), alloy slag.

A. *Industrial by-products:*

Industrial waste is escalating from time to time and as per reports, only around 15% of the industrial waste material is utilised and the rest is disposed into landfill [7]. To countervail the shortage of exhaustible materials, industrial waste materials need to be brought into service. This will not only help to untangle the disposal issue, but will also assist in finding an alternative material which will in-turn safeguard the environment. There are a variety of industrial wastes that can be used as partial or full replacement of fine aggregate [8].

I. *Copper Slag:* Copper slag (CS) is produced in gigantic proportion from copper manufacturing units and can be used as a potential replacement to natural river sand in engineering applications [10, 13]. It is obtained from the matte smelting and honing of copper metal from the industries [9,11]. During the refining process, the yield of copper slag as by-product is round about thrice the production of copper metal [11,12]. Since, in our country, there is lack of treatment plan for this waste and therefore paves way for usage of copper slag as an alternative to natural river sand. The presence of copper slag improves the properties of concrete by virtue of its excellent characteristics [13].

II. *Coal Bottom Ash:* Coal bottom ash (CBA) is devised in coal furnaces. Bottom ash is a proportion of the non-combustible residue of combustion in a furnace or a power plant. The ash assembled at the base of furnace is entitled as CBA which makes about 25% of the entire coal ash. CBA is commonly comprised of coarser and popcorn-like particles [14]. The employment of CBA will be beneficial in three modes: 1. safeguarding the environment from ill effects caused by the dumping of CBA in bare land; 2. decrement in its manufacturing cost; 3. protecting the atmosphere from CO2 emissions [15].The physical peculiarity of CBA resembles with natural sand and that makes it an advisable material in substituting sand. For the replacement of fines, the ideal proportion of CBA is 15% as per studies conducted. After certain proportion, it is commonly accepted that the mechanical properties are improved with decrease in CBA percentage [16].

III. *Iron Slag:* From the past few years, the steel industries have seen much of a boost in order to meet the growing pressure of construction [42]. As a result of this, enormous amount of iron slag is generated which is disposed-off later. One of the best ways of utilising iron slag is in the construction industry to produce sustainable end product. This will, indeed, preserve the landfill area and lessen the withdrawal of exhaustible materials [32, 42].

IV. *Waste Foundry Sand (WFS):* Waste foundry sand is a sand-bases by-product which is acquired from dismantling of moulds. It is composed of high quality, low cost silica sand (90%), some percentage of pulverised coal (2-10%), 3% chemical binder or 10% bentonite clay as innate binder. The disposal of this waste sand in landfills cause environmental problems and, hence, by putting WFS to use can solve this problem and also provide an alternative to river sand [17, 18]. Various studies suggest that incorporation of WFS up to 20-30% replacement yield satisfactory results [17]. Around 35,000 foundries are set-up across the globe having a production of nearly 90 million tonnes. India ranks second in terms of the number of foundries having a score of 9374 and the annual waste foundry sand production is roughly around 2 million tonnes [19, 20].

III. PHYSICAL PROPERTIES

Physical properties of various alternative fine aggregates help in determining their behaviour and hence are very important to be discussed. Different physical characteristics such as specific gravity, fineness modulus and water absorption percentage have been discussed under this category

A. *Physical Properties of Industrial by-products:*

The various physical properties of different industrial by-products have been listed separately.

1. *Physical Properties of Copper Slag:* The various physical characteristics of copper slag are tabulated in Table I. Copper slag is usually black in colour and possesses glassy texture. The particle size is almost similar to natural river sand. The specific gravity and fineness modulus vary from 3.4 to 3.97 and 3.28 to 3.47 respectively. Copper slag particles are highly dense and crystalline which results in lowering surface porosity, thereby, reducing water demand.

TABLE I PHYSICAL PROPERTIES OF COPPER SLAG

Author	**Appearance**	**Specific Gravity**	**Fineness Modulus**	**Water Absorption (%)**
N. Gupta et. al	Black,Glassy texture	3.51	3.11	0.36
Chao-Qunet al	Black and Glassy	3.97	-	0.10
V. Karthik et al	Black and Glassy	3.93	3.28	0.18
D. Brindha et al	Black and Glassy	3.91	3.47	0.15 to 0.20

2. *Physical Properties of Coal Bottom Ash:* The physical characteristics of coal bottom ash are listed in Table II. CBA is traditionally dark grey in colour and has less unit weight. The fineness modulus and specific gravity varies from 1.37 to 3.44 and 1.39 to 2.45 respectively. The variation in these values is due to dissimilarity in type of parent coal and process of grinding. The lower values are also due to the porous nature of CBA.

TABLE II PHYSICAL PROPERTIES OF COAL BOTTOM ASH

Author	**Specific Gravity**	**Fineness Modulus**	**Water Absorption (%)**
M. Rafieizonoozet	1.88	3.44	11.61
S.K. Kirthika et al	1.87	2.36	8.10
Ghafoori and Bucholc	2.45	2.8	7.0
L.B. Andrade et al.	1.674	-	-
M.Singh et al	1.39	1.37	31.58

3. *Physical Properties of Iron Slag*: The physical features of iron slag are listed in Table III. Iron slag is generally black and possesses glassy presentation.

The specific gravity is around 2.49-2.50 and the fineness modulus around 2.38-2.72.

TABLE III PHYSICAL PROPERTIES OF IRON SLAG

Author	Appearance	Specific Gravity	Fineness Modulus	Water Absorption (%)
G. Singh et al.	Black, glassy	2.49	2.38	18.54
Vijayaraghavan et al.	Black, glassy	2.49	2.72	-

4. *Physical Properties of Waste Foundry Sand:* The physical characteristics of waste foundry sand are listed in Table IV. It is generally dark grey to black in colour based on amount of carbon present. The properties are influenced by the type of casting process and parent industrial sector. The specific gravity varies from 2.18 to 2.63. The lower value of fineness modulus is because of the clay present in WFS which in turn escalates the demand of water.

TABLE IV PHYSICAL PROPERTIES OF WASTE FOUNDRY SAND

Author	Specific Gravity	Fineness Modulus	Water Absorption (%)
Martins et al	2.61	0.51	-
Rafat et al	2.43	1.23	1.21
Singh G. et al	2.18	1.89	0.42
Bhimani D. et al	2.47	-	0.45
Bhardwaj B. et al	2.38	1.82	2.71
Torres et al	2.45	1.7	1.4
Chitroju et al	2.63	-	1.9

IV. CHEMICALCHARACTERISTICS

Physical characteristics of various alternative fine aggregates help in identifying the presence of various chemical compounds and also are very important to be discussed. Chemical compositions of various alternative fines have been discussed under this category.

A. *Chemical Characteristics Industrial by-products*

The chemical characteristics of industrial by-products are given in Table V, Table VI, Table VII and Table VIII respectively.

I. *Chemical characteristics of copper slag:* The percentages of various chemical constituents are listed in Table V. The major constituents are iron, silica, alumina and calcium. The higher percentage of silica, alumina and iron oxide makes copper slag a good pozzolanic material.

TABLE V CHEMICAL CHARACTERISTICS OF COPPER SLAG

Authors	SiO_2	CaO	Al_2O_3	Fe_2O_3	MgO	K_2O	Na_2O
Sharma et. al.	30.53	1.6	2.8	57.82	1.48	0.71	0.34
Chao-Qun et al.	33.0	6.06	2.79	53.5	1.56	-	-
Gupta et al.	33.62	3.31	3.65	55.60	1.51	0.82	0.37
Karthik et al.	21.13	0.17	0.23	63.3	-	0.31	0.62
Al-Jabri et al.	33.05	6.06	2.79	53.45	1.56	0.61	0.28

II. *Chemical Characteristics of Coal Bottom Ash:* The chemical characteristics of coal bottom ash are listed in Table VI. It contains higher percentage of silica, iron and alumina and low percentage of magnesium, calcium and sulphate. The variation in chemical content is because of difference in type and quality of coal. As the percentage of major oxides is high, CBA exhibits pozzolanic properties

TABLE VI CHEMICAL CHARACTERISTICS OF COAL BOTTOM ASH

Authors	SiO_2	Al_2O_3	Fe_2O_3	K_2O	Na_2O	CaO	MgO
Rafieizonooz et al	45.3	18.1	19.8	2.4	-	8.7	0.9
Ghafoori et al	41.7	17.1	6.63	0.4	1.3	22.5	4.9
Andrade et al.	56.0	26.7	5.8	2.6	0.2	0.8	0.6
Kusbiantoro et al	42.6	15.4	17.8	1.2	1.7	11.8	11.
ErtugAydin	55.1	28.1	8.3	1.5	-	1.1	0.3
Singh et al	56.4	29.2	8.4	1.2	0.1	0.7	0.4

III. *Chemical Characteristics of Iron Slag:* The chemical characteristics of iron slag have been tabulated in Table VII. Clearly, iron slag is rich in silica and iron content. The variation seen in chemical constituent percentage depends upon the nature and type of iron and industry.

TABLE VII CHEMICAL CHARACTERISTICS OF IRON SLAG

Authors	SiO_2	Al_2O_3	Fe_2O_3	CaO	MnO	K_2O	Others
Shettima et al	56.0	10	8.3	4.3	1.7	1.5	0.7
G.Singh et al	6.98	2.94	66.88	0.8	-	-	22.40
Han et al	67.29	8.49	8.95	3.63	-	-	8.3

IV. Chemical Characteristics of Waste Foundry Sand: The different chemical constituents of waste foundry sand are provided in Table VIII. Foundry sand has high silica content (76% - 95%) and its particles are surrounded by a layer of burnt carbon, dust and residual binder

TABLE VIII CHEMICAL CHARACTERISTICS OF WASTE FOUNDRY SAND

Author	SiO_2	Al_2O_3	CaO	K_2O	Na_2O	MgO	Fe_2O_3
De Matos et al	78.1	9.69	0.98	1.10	1.07	1.01	3.50
Singh G. et al	83.8	0.81	1.42	1.14	0.87	0.86	5.39
Bhimani D et al	87.91	4.70	0.14	0.25	0.19	0.30	0.94
Sahmaran et al	76.0	4.45	3.56	1.20	0.38	1.98	5.06

Torres et al	94.1	1.7	0.2	-	-	-	5.8
Chitroju et al	83.93	0.021	1.03	-	-	1.77	0.950

V. PROPERTIES IN FRESH STATE

The fresh properties of SCC include filling and passing ability and it should be in accordance with the EFNARC [2] guidelines. It also includes resistance to segregation but that is something which can be observed visually. The EFNARC criteria to check whether filling and passing ability properties are satisfactory for the formation of self-consolidating concrete are listed in Table IX

A. Filling Ability

One of the most important features that determine the self-compacting ability of a concrete is its filling ability. The particle shape and micro-roughness has an impact on the filling ability, but the amount of fines and the clay lump content have more significant effect. The non-porous and lower absorption nature of the copper slag particles proves beneficial for SCC and results in an increase of slump flow [9,22]. The flow increased from 690mm to 725m at 100% of slag substitution. The T_{500mm} time was also found to lessen with increasing percentage of copper slag since the water absorption characteristic of CS particles is lower [9, 10, and 12]. However, Karthik et al [23] reported marginal variation in the slump flow till 60% CS substitution after which significant drop was observed. The T_{500mm} time increased slightly up to 60% substitution and then increased at greater extent [23]. A graph showing the variation of slump flow for copper slag is given in Fig. I.

TABLE IX CRITERIA FOR SCC (EFNARC 2005)

S.No	Test	Property	Class	Range
1	Slump flow test	Filling ability	SF1	(550 to 650)mm
			SF2	(660 to 750)mm
			SF3	(760 to 850)mm
2	T500mm	Viscosity	VS1	≤2s
			VS2	>2s
3	V-Funnel Test	Viscosity	VF1	≤8s
			VF2	(9-25)s
4	L-Box Test	Passing Ability	PA1 (2 rebars)	≥0.8
			PA2 (3 rebars)	≥0.8
5	J-Ring Test	Passing Ability		(0-10)mm

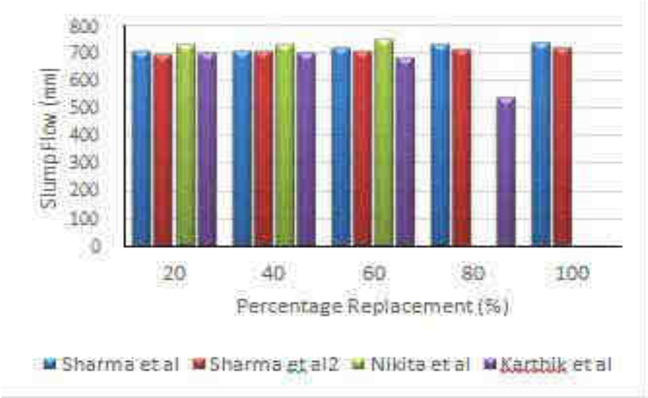

FIGURE I SLUMP FLOW VARIATION FOR COPPER SLAG

Fig. II shows the representation of variation in slump flow for CBA. As evident from the figure, the inclusion of coal bottom ash (CBA) as fine aggregate in SCC reduces the slump flow and consequently increases the T_{500mm} values [24-27]. Such behaviour could be explained by the fact that CBA absorbs higher amount of water [25]. Kasemchaisiri et al and Ernida et al [26,27] replaced natural sand with coal bottom ash and concluded that there was a reduction in slump flow due to the effect of uneven texture of the CBA particles that cause enough friction.

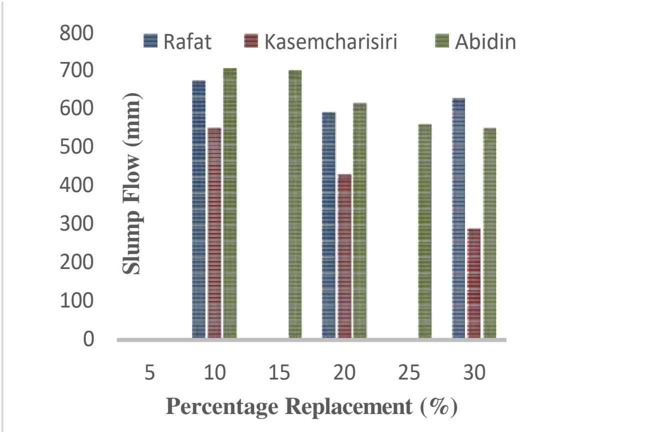

FIGURE II SLUMP FLOW VARIATION OF CBA

A typical graph showing the variation of slump flow for WFS is given in Fig. III. Adequate slump spread was obtained till 40% replacement of fine aggregate by most of the researchers. The replacement of natural fine aggregates by waste foundry sand slightly decreases the slump flow when compared with conventional SCC [28]. At 20% replacement, slump flow was observed to reduce by 2.5% which can be ascribed to the presence of clayey fines [29]. Increase in water demand of WFS was found to be the reason responsible for reduced flow [30]. However, Sanjay et al [31] reported higher slump flow at 20% replacement of waste foundry sand when granite waste was added as cement filler.

The incorporation of iron slag resulted in decrease of slump flow. The possible decrease could be due to the effect of granulated and sharp- edged particles of iron slag which results in inter-particle friction. There was 6.3% decrease in flowability as the percentage of iron slag increased from 10% to 40% [32,33].

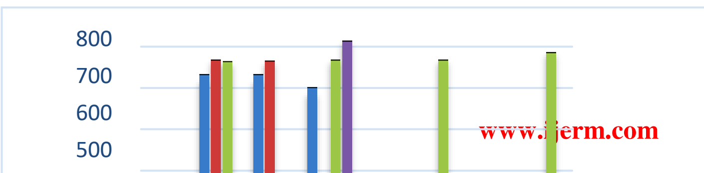

FIGURE III SLUMP FLOW VARIATION FOR WFS

B. *Passing Ability:*

L-Box results indicate that as the percentage addition of copper slag is increased, the H2/H1 ratio also increases. The value raised from 0.84 at 0% CS to 0.93 at 100% CS substitution [9, 10 and 12]. Further, Karthik et al [23] found that the L-box ratios remained more or less the same, i.e., around 0.9, except at 80% CS where the value increased to 1.3. N.Gupta et al [22] noticed similar rise pattern in L-Box ratio when the percentage of CS was increased from 0% to 60% [22].

L-Box test when performed in case of CBA, was found to increase at 10%, 20% and 30% inclusion [24]. With increasing percentage of CBA, the L-box (H2/H1) ratios were found to decrease. However, at 10% substitution of natural river sand with CBA, the results were almost similar to that of normal SCC developed with natural sand [25]. Similar observations were made where the passing ability of the developed SCC samples decreased increasing percentage of CBA. However, beyond 20% substitution of natural sand by CBA, blockage was noticed. This might be due to the result of excessive inter- particular friction between the CBA particles [26,27]

L-Box test was conducted on the samples with varying percentage of WFS in SCC. At 100% natural river sand, the H2/H1 ratio was reported to be 1.0. Moreover, when the percentage of WFS was raised from 0% to 10%, 15% and 20%, the H2/H1 ratio noticed was 0.9, 1 and 0.8 respectively. Similarly, the U-box test results were in the range of 5mm-23mm [29]. Incorporation of 10%-15% WFS and 5% waste tyre rubber as substitution of coarse aggregate, the results depicted that the H2/H1 ratio kept on decreasing [30]. Despite reduction in fresh properties due to increase in water demand, the calculated values fall within the limit of EFNARC [2] guidelines and hence the results are satisfactory. J-Ring and H-Box tests were carried out. On varying the replacement percentage of WFS as 10%, 20%, 30%, 40% and 100%,the corresponding values of J-ring were reported as 6.0, 6.5, 6.3, 7 and 7.3mm and the H-Box (H2/H1 ratio) values were 0.85, 0.99, 0.89, 0.867 and0.91 respectively. All the reported values are satisfactory and do not influence the passing ability of the SCC developed with WFS [28]. J-ring [21] and L-Box test was performed for two specimens; one having 100% natural river sand and other having 20% waste foundry sand and 10% granite waste powder, the corresponding values were 8mm and 0.85, and 8.7mm and 0.92 respectively. This shows the incorporation of waste foundry sand does not jeopardize the passing ability of the developed SCC [31].

To check the effect of iron slag on the passing ability of SCC, L-Box test was conducted. It was seen that as the percentage of iron slag increased, H2/H1 ratio was found to decrease. At 0% iron slag substitution, the ratio was 0.9 and at 10%, 25% and 40% iron slag substitution the corresponding ratio was 0.87, 0.86 and 0.85 [32, 33]. Nonetheless, all the values are within the boundaries of EFNARC [2].

VI. PROPERTIES IN HARDENED STATE

A. *Compressive Strength*

The compressive strength initially increased at 20% CS inclusion and then decreased marginally till 100% CS substitution of river sand. Strength reduction beyond 60% was recorded because of the glassy texture of CS particles and due to rise in free water content [9, 10, 12 and 22]. Fig. IV shows the variation in compressive strength at different substitution levels of copper slag.

With the inclusion of CBA, the 28days compressive strength was found to be more or less the same up to 10% substitution. decrease. However, at higher replacement levels, the compressive strength was found to decrease. This can be explained by the fact that with increasing CBA percentage, the porosity of hardened SCC increases [24,26].

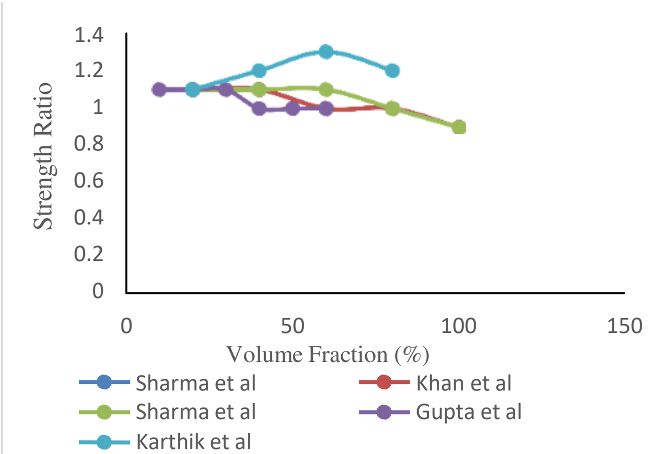

FIGURE IV VARIATION OF COMPRESSIVE STRENGTH WITH INCREASING PERCENTAGE OF COPPER SLAG.

A decrease in compressive strength could be seen with the rising percentage of CBA. Despite decrease in compressive strength, at 10% CBA substitution, value came out to be 38.1MPa which is pretty much comparable to the SCC developed with 100% natural sand [25]. compressive strength recorded was nearly. The compressive strength of SCC was found to enhance by around 13.6% when 10% CBA was used as fine aggregate and the same increased by 22% at 15% CBA replacement, but beyond 15% substitution of CBA, a considerable loss in strength was observed. The increase in strength can be as a result of its pozzolanic activity in which the silica quantum contributes towards enhancing the configuration of C-S-H gel [27]. Fig. V represents the variation in compressive strength at different CBA replacement levels.

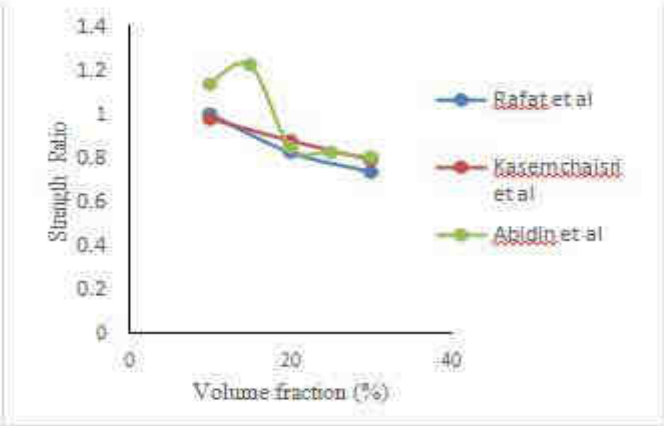

FIGURE V VARIATION IN COMPRESSIVE STRENGTH WITH INCREASING PERCENTAGE OF CBA

With the rise in the percentage of waste foundry sand in self-compacting concrete, the 28days strength was found to increase. Better results were attained at 15% substitution of natural river sand by WFS. The strength at 28days for the samples with 0%, 10%, 15% and 20% WFS was reported to be around 36MPa, 40.5MPa, 43MPa and 40MPa respectively. It was also found that at 15% usage of WFS, the early day strength at 7days, increased roughly by 35% as compared to 0% usage of WFS [41]. Shetty et al [34] studied the influence of waste foundry sand on self-compacting concrete with small percentage of red mud as a substitute to cementing material. On replacing natural sand by10% of waste foundry sand along with replacement of 2% cementing material with red mud, an increase in strength was reported. Thus, an addition of around 15.4% can be seen by the incorporation of 10% WFS and 2% red mud. When the self-compacting concrete is developed using 10% WFS as substitution of river sand along with 5% waste tyre rubber as replacement of coarse aggregates, the strength showed an inclination of 9.86% [30].With the incorporation of WFS in SCC as replacement of river sand, the strength was found to increase slightly and then decrease when the percentage of WFS was raised from 0% to 100%. At 20% substitution of natural sand by WFS, compressive strength was found to increase by 6.06%. However, at complete replacement, the strength declined by 23.4%. Compressive strength enhanced by 5.1% when metakaolin admixture up to 10% was added along with WFS [62]. Sanjay S J et al [31] prepared M 50 grade self-compacting concrete and reported 6.5% rise in strength when the 10% of river sand was replaced by WFS. Fig. VI shows a graphical representation of variation in compressive strength at different WFS substitution percentages.

The 28days compressive strength of the samples containing iron slag increases when compared with control SCC. The strength was found to increase by 1%, 13% and 20% respectively at 10%, 25% and 40% incorporation of iron slag as partial substitution of river sand. It can be understood from the fact that reactive silica in iron slag reacts with alkali $Ca(OH)_2$ and forms calcium silicate hydrates (CSH gel) which ends up in packing the voids and thereby enhances compressive strength [32, 33].

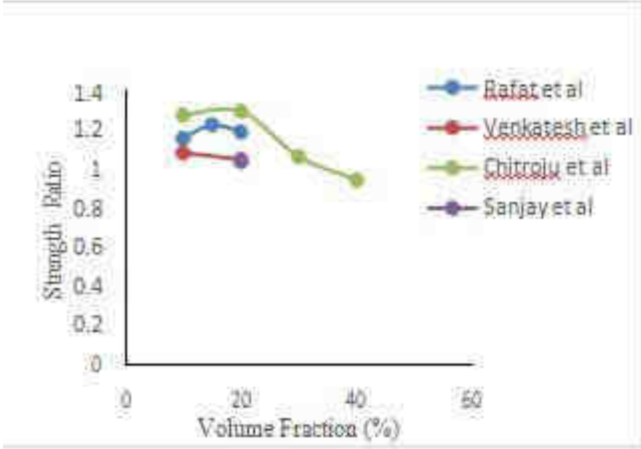

FIGURE VI VARIATION IN COMPRESSIVE STRENGTH WITH INCREASE IN PERCENTAGE OF WFS.

B. Splitting Tensile Strength

The splitting tensile strength of SCC prepared with copper slag is found to be higher than the control concrete. The increase in the replacement percentage of CS resulted in further rise of strength. The rise in strength may be due to the action of angular grains of copper slag particles that enhanced binding of the concrete matrix [12, 22]. Fig. VII shows the variation of splitting tensile strength at different CS replacement percentages.

Incorporation of CBA by increasing its percentage yielded negative results as the declination in splitting tensile strength was noticed. At 0% substitution of natural sand, the value was 2.68MPa and at 30% replacement, the value was brought down to 2.05MPa [24]. The strength was found to decrease gradually with the addition of CBA. The splitting tensile strength came down from 4.3MPa at 0% CBA to 3.1MPa at 30% CBA [25]. Fig. VIII shows variation in splitting tensile strength at different CBA percentages.

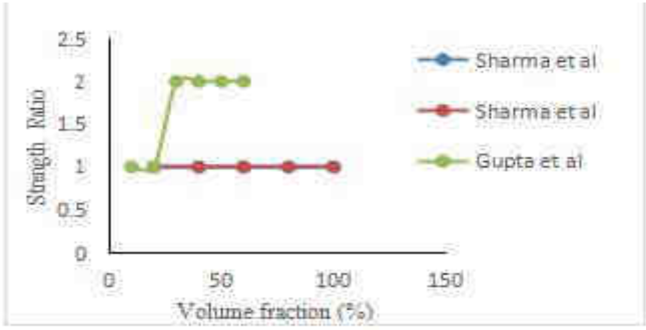

FIGURE VII VARIATION IN SPLITTING TENSILE STRENGTH WITH INCREASING PERCENTAGE OF COPPER SLAG

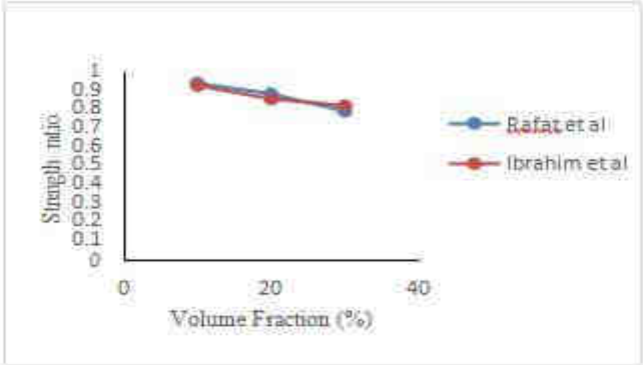

FIGURE VIII. VARIATION IN SPLITTING TENSILE STRENGTH WITH INCREASING PERCENTAGE OF CBA

There was an increase in the splitting tensile strength of self-compacting concrete with the incorporation of WFS. As the proportion of WFS is increased, the splitting tensile strength also enhances. By varying the percentage of WFS from 0% to 20%, the 28days splitting tensile strength was reported to be 2.8MPa, 3.3MPa, 3.5MPa and 3.35MPa respectively. The early strength was found to be more or less the same in all cases, but the better results were obtained by replacing river sand by 15% of WFS [29]. A slight decrease in strength was detected with 10% incorporation of waste foundry sand. Replacement of 4% of cementing material with red mud resulted in less decrease of strength [34]. Positive results were reported when 10% waste foundry sand was used as partial substitution of river sand. The splitting tensile strength was found to enhance by 14.19% [30]. Approximately 30% higher splitting tensile strength was reported by Chitroju et al [28] when 20% WFS was used to replace river sand. While designing M50 grade self-compacting concrete, the specimen with 0% WFS recorded strength of 3.94MPa while as the other specimen with 20% WFS recorded a higher value of 4.36MPa [31]. With the inclusion of iron slag as partial substitute to river sand, splitting tensile strength was found to enhance. At 10%, 25% and 40% usage of iron slag, the splitting tensile strength increased by 3.5%, 16% and 21% respectively [33]. Fig. IX shows a graphical representation of variation in splitting tensile strength at different replacement levels of WFS.

C. Flexural Strength:

Venkatesh P et al [30] evaluated the effect of addition of 10% WFS and observed that the strength was raised by 7.54%. A slight improvement in the flexural strength was observed when 20% waste foundry sand was incorporated. The percentage rise in strength was reported to be around 10.39% [31]. A comparable rise in flexural strength was recorded with the addition of iron slag as partial substitution to river sand. A strength gain of 1%, 5% and 14% was seen at 10%, 25% and 40% usage of iron slag in self-compacting concrete [33].

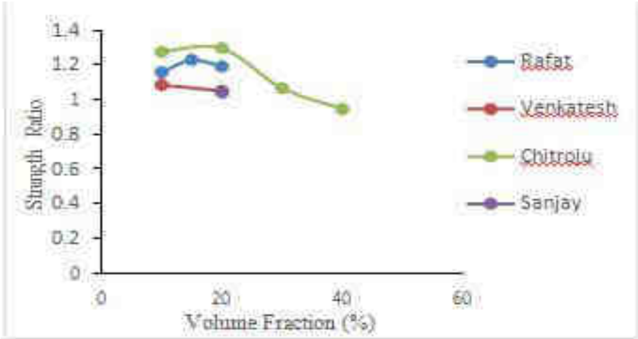

FIGURE IX VARIATION IN SPLITTING TENSILE STRENGTH WITH INCREASING PERCENTAGE OF WFS.

D. Water Absorption:

The incorporation of coal bottom ash in SCC as fine aggregate increases the water absorption rate. It was found that the increase in percentage of CBA by 30% results in 22.4 % rise in water absorption values [24]. At 10% and 15% substitution of CBA, rate of water absorption was found to decrease. However, beyond 15% inclusion of CBA, the water absorption rate increased. The decrease in water absorption rate is due to the effect of finer particles of CBA that act as filler and reduce the pores of SCC and the increase after 15% CBA is due to porous structure of SCC with the provision of excessive volume of CBA [27]. Water absorption percentage at 28days was found to decrease with rise in the percentage of iron slag. The water absorption percentage at 0% incorporation of iron slag was 4.81% which decreased by 1.5, 12 and 4% respectively at 10%, 25% and 40% inclusion of iron slag. The reason for decrease in water absorption is due to the effect of iron slag, the structure of SCC got denser [32].

DISCUSSION

For sustainable and eco-friendly construction, different alternative fines can be used as a substitute to river sand. The industrial by-products can be used as fine aggregates instead of disposing them off. This paper studies the existing research on the substitution of natural sand by alternative fine aggregates and illustrates that the use of these alternative fines helps in maintaining environmental balance and improving the properties of SCC up to a specific substitution ratio.

A. Current Challenges:

Although different types of alternative fines are available that can be efficiently used in self-consolidating concrete, yet there are various challenges which impede its large-scale application. Studies reflect that the variation in material composition is due to difference in manufacturing process and quality of raw materials used. These factors are responsible for the variation in the experimental results. Developing the standard conditions for the production of industrial material is a big challenge currently being faced. It will ensure uniformity in the composition. The limited research in this field is also because of inadequate back up from the government and lack of awareness among people.

B. Research Gaps:

On the basis of literature review carried out, following are some of the research gaps that have been pointed out for future research:

- Detailed study for the utilisation of alternative fines in self-consolidated concrete and its impact on fresh and hardened properties.
- Development of standard method for the manufacturing of industrial products.
- Research regarding lowering the porosity of coal bottom ash by some cost-effective treatment.
- Additional experimental work needs to be done on durability properties of alternative fines and their effect on SCC.

CONCLUSION:

While plenty of study has been conducted on the use of alternative fines in traditional concrete, there are only a few cases of its incorporation in SCC. Given below are some conclusions drawn on the basis of the review work done:

1. The density of CBA is low and therefore can be preferably used for the construction of light-weight sections. On the other hand, WFS can be used for construction of denser sections due to low porosity.
2. Certain industrial by-products such as copper slag, iron slag, coal bottom ash and waste foundry sand have some pozzolanic properties which enhances strength when substituted up to a specific limit.
3. CBA substitution up to 10% is acceptable and showed good durability results. Copper slag up to 60% substitution enhances both fresh and hardened properties of SCC and WFS up to 15% substitution has a good impact on SCC as it boosts fresh and hardened properties.
4. Copper slag is an exemplary advantageous material that can be put to use in SCC with less water demand. It also eliminates the problems of poor flowability.
5. Usage of both mineral and chemical admixtures in industrial by-products enrich the fresh and hardened properties of self- consolidating concrete.

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