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REVIEW ARTICLE

Ferrochrome slag and manufactured sand as fine aggregate replacement in concrete and mortar - A Brief Review

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Abstract

Background/Objective: To review on the river sand supplants particularly Manufactured sand (Msand) and Ferrochrome slag (FeCr slag) aggregate in concrete and mortar matrix. **Methods**: A study on FeCr slag as sand is skimpy and countable; so here they clustered together and discussed for its performance..Msand by its shape, texture, physiochemical characters, strength parameters and durability is much similar to river sand in a concrete matrix. FeCr slag shape and texture is almost similar but porous in nature and ingredients like MgO and Cr_2O_3can cause an effect on concrete. Msand based on various grades and mechanical strength is analysed. **Findings**: Msand strength behaviour is discussed in detail with reference to other authors which clearly states that Msand is ideal for fine aggregate replacement. Industrial waste FeCr slag is replaced instead of sand, which also behaves well until 40% to 50% replacement of sand at later ages of strength. Compressive strength, splitting tensile strength and flexural strength of these two materials are graphically depicted from a literature surveys of recent researches. **Novelty**: This study provides robust information about strength performance of Msand and FeCr slag with varying percentage ranges from 10% to 60% by weight.

Keywords: Msand; ferrochrome slag; strength; compressive; splitting; flexural; river sand

1 Introduction

In this techno-modern world, concrete is a major composite used to develop the infrastructure like bridges, dams, commercial and residential structures. In general, concrete comprises 70 percentage of aggregate fillers. Whereas, fine aggregate occupies 50% of aggregate volume in concrete. In Tamil Nadu, nearly 10 million Cubic feet sand is required per day, where the cost for 1cubic feet is 143 Indian rupees. Also it leads to the destruction of natural resources from river sand and reduces the ground water level around river belt region. In order to preserve the natural resources in its pristine form, an alternate for river sand is essential to maintain ecological balance and preserve the environmental sources for future generation.

Industrial by- products like Foundry sand (FS) and Steel slag are already supplanted for sand. FeCr slag from ferrochrome ore extraction industries can be grained to the required size and to fall on zone condition for concrete. India is the second largest steel producer in the world next to China. In the production of stainless steel, ferrochrome plays a paramount role. While extracting ferrochrome from its ore we get almost 50% FeCr slag. As per International Chromium Development Association (ICDA) activity report 2017, nearly 13.2 Million tonnes (Mt) of FeCr slag are produced from 13 major chromium production countries. Some of the leading producers are China, South Africa, Kazakhstan and India. India lets nearly 1.5 to 2 Mt per year. FeCr slag is liquid in state and it is allowed to cool for a few days in wasteland and it is dumped into the larger part of eastern parts of India like Odisha and Andhra Pradesh. It occupies large dumped areas and creates a lot of nuisance for the society, these waste materials can be used in concrete instead of fine aggregate.

There are a number of studies carried out with this slag as coarse aggregate; on the contrary, very few researches carried out with FeCr slag as fine aggregate. Studies on Crushed Stone sand or Msand is gaining momentum throughout Tamil Nadu after banning River sand consumption for construction. One cubic feet of Msand is around 65 Indian rupees. Moreover, TNPWD (Tamil Nadu Public Work Department) approved some plants to grain the boulders and rocks as fine aggregate which follows IS 383 2016. There are two different varieties of Msand based on the use. They are Msand for concrete and Msand for plastering. Msand for concrete is slightly coarser in texture; whereas, Msand for plastering is finer. Numerous Indian authors experimented and analysed the Msand for concrete based on various physicochemical characters like geographical condition of stone, shape, texture, particle size, chemical composition and other ingredients in the mix.

Existing researchers have discussed the usage of Msand with different percentage of replacements for a particular grade of concrete. The comprehensive view of Msand in different grades of concrete are not yet deliberated so far.

2 Comprehensive Literature

Mortar study was conducted with FeCr slag. It retained the flowability of mix and it has high thermal conductivity due to MgO and Cr_2O_3 content in slag. .Hence FeCr slag leads to reduction of thermal stress and temperature gradients. Three dimensional surface topography of FeCr slag shows sharp needle than river sand which leads to the brittle nature [1]. FeCr Slag has Hexavalent chromium (CrVI),which is mobilised at pH below 5 and Trivalent chromium (CrIII) is immobilised due the spinal phase of magnesium chromite in concrete. Total Chromium leaching is also within the limit as per Building Material Decree (BMD) [2]. Chloride ion penetration is very low in 10% replacement of FeCr slag in concrete, but 20% to 50% replacement ranges from 1000 to 2000 coulombs respectively at 28 and 91 days. Mechanical strengths are increased up to 30% replacement of FeCr slag instead of virgin sand [3]. Hexavalent chromium and Total chromium cause skin ulceration, lung diseases and other health problems, if it exceeds the limit of USEPA 1992. Toxicity characteristic leaching procedure (TCLP)Method 1311 and Ministry of Environment and Forests, Government of India. Further, CrVI and total chromium are below the limit, it does not cause any adverse effect on health and environment. Hence, it implies that there is 30% to 40% of supplant FeCr slag in concrete matrix, which is suitable as traditional sand [4]. FeCr slag, which has a Chromium immobilization phase in concrete cluster is supplanted instead of river sand [5]. Crushing, splitting and flexural results of three various curing like water, acid and base are tested on7 days and 28 days,thereby strengthening 40% replacement of FeCr slag in concrete [6,7]. Nano Metakaolin (NMK), while incorporating with FeCr slag in mortar gives a better thermal property, strength, reduced shrinkage on drying and water absorption. Drying shrinkage of 100% sand and Portland cement have -233 microstrain on the 28th day. However, 10% NMK incorporating binder with 50% of FeCr slag in the sand reduces micro strain to -27.5. Thermal conductivity of control is 1.6 W/m.k. Optimum with NMK and FeCr slag, thermal conductivity surged to 2.6 W/m.k. In capillary water absorption, control mix is 0.33 Kg/m^2 $min^{1/2}$. Moreover, optimum is 0.15 Kg/m^2 $min^{1/2}$, that enhances the service life of structure and durability of matrix with NMK and FeCr slag. Hence,the author recommends that 50% mass of FeCr slag can be replaceable in motar, which can reduce the consumption of natural resources and heaps of slag in land filling [8]. Msand in mortar does not much reduce Modulus of Elasticity and strength parameter; these recommend Msand can be replaceable fully or partially in mortar instead of river sand [9]. Ultra High Strength Concrete (UHSC) with Msand gives better performance than river sand. UHSC microstructural studies explain a better dense structure with monosulfoaluminate (AFm), trisulfo aluminate(AFt), calcium hydroxide (CH) and Calcium Silicate Hydrate (CSH)gel [10]. Length-width ratio and roundness of Msand are higher than river sand; surface roughness of Msand is lower than river sand. For same water binder ratio Msand gives better strength than traditional sand [11]. Dwindling of natural sand is avoided by replacing 50% of Msand in high performance concrete based on the study of mechanical strength [12]. Cohesive concrete with Msand can replace riversand, which gives a better strength at 60% weight replacement of Msand inside the concrete [13]. Mortar study on Msand with 0.5 and 0.55 water cement ratio for 1:2 and 1:3 are done, based on the result behaviour, 50% of Msand replacement with sand is favourable in the mortar matrix [14]. Angularity of Msand concrete is less workable than traditional sand mix, 28 days compressive strength of Msand performance is 10% higher than the river sand strength at 100% replacement of Msand in concrete cluster[15]. Msand workability is decreased due to particle shape of Msand than the conventional sand. Workability issue in Msand can be screwed by increasing chemical admixtures dosage in concrete. Although 60% of Msand shows good result in compressive, split and flexural result than other replacement mix. Also in acid treatment, 60% of Msand gives a better outcome than the other percentage of replacement[16]. A water binder ratio of 0.48 and 0.5 is experimented, and strength for lower water binder ratio is higher. The compressive strength result shows the 60% weight of Msand replacement behaviour is the best and in splitting tensile strength 40% of Msand replacement shows a better outcome in concrete matrix[17]. Msand in 15% replacement gives a higher strength values than the other replacement at compressive and split experiment after 28 days curing[18]. Binder as Ordinary Portland Cement(OPC) with 10% silica fume is tested with 0 to 100% replacement of Msand. In compressive and flexural strength, fully replaced matrix gives a good result. An RC column with 100% Msand and 100% river sand are studied under axial loading, where Msand mix shows less crack pattern than conventional sand mix. The load carrying capacity of Msand cluster performance 27% higher in HPC. Hence 100% replacement of Msand is recommended by the author[19]. Geopolymer concrete (GPC) and conventional concrete with 100% Msand are studied. GPC with sodium hydroxide (NaOH) and sodium silicate (Na_2SiO_3) solution are used. According to durability study, GPC performance is better than cement concrete[20].

Table 1. Summary of using ferrochrome slag and manufactured and as fine aggregate

Reference	Study area	MC	SG	Z	TB	RP	w/c	WA	FM	Analysis
1	Mortar	River Sand	2.85	II	OPC	0%, 5%, 10%, 15% and 20%	0.485	0.63	-	Mechanical strength, Micro structural, drying shrinkage, Thermal property, and XRD.
2	Concrete	River Sand	2.72	I	OPC, PPC and PSC	0%, 20%, 40%, 60%, 80% and 100%	0.5	0.42	4.8	Compression, TCLP, SQD and BMD.
3	Concrete – M30	River Sand	2.52	II	PSC	0%,10%, 20%, 30%, 40% and 50%	0.42	1.01	2.33	Mechanical strength, UPV, MOE,RCPT, optical microscopic study acid and sulphate resistant
4	Concrete – M30	River Sand	2.38	II	OPC	0%,10%, 20%, 30% and 40	0.43	-	2.38	Mechanical strength at water, acid and base curing.
5	Concrete – M30	Natural Sand	2.52	II	PSC	0%,10%, 20%, 30%, 40% and 50%	0.42	10.89	2.69	Slump Loss, Mechanical strength, water absorption, SAI, TCLP, SEM
6	Concrete – M30	River Sand	2.52	II	PSC	0%,10%, 20%, 30%, 40% and 50%	0.42	10.89	2.69	Review
7	Mortar	River Sand	2.85	II	OPC with Nanometakaolin	50% FeCr	0.485	-	-	Mechanical strength, Micro structural, Sorptivity, Drying shrinkage, Thermal property, and XRD.
8	Concrete – M30	River Sand	2.38	II	OPC	0%,10%, 20%, 30% and 40	0.43	-	2.38	Mechanical strength at water, acid and base curing.
9	Mortar	River Sand	2.65	II	OPC	0%, 20%, 40%, 60%, 80% and 100%	0.5, 0.6, 0.625, 0.65 0.7, 0.8, and 0.825	1.01	2.7	Percentage of Flow,SEM, Compressive strength and Modulus of Elasticity

Continued on next page

Table 1 continued

Reference	Study area	MC	SG	Z	TB	RP	w/c	WA	FM	Analysis
10	UHSC	River Sand	-		OPC with silica fume, fly ash and GGBS	100% of sandstone, limestone and granite as Manufactured sand	0.17 to 0.19	-	-	Slump, compressive strength, SEM and Elemental mapping.
11	Concrete - M60	River Sand	-		OPC with Fly ash	100% of various Lithology manufactured sand	0.34	-	2.26 to 3.69	Slump, compressive strength, XRD, surface roughness.
12	HPC	River Sand	2.56	II	OPC with Silica fume	0%,30%,50% and 70%	0.32	-	3.10	Compressive strength and flexural strength
13	Concrete – M20	River Sand	2.84	II	OPC	0%, 20%, 40%, 60%, 80% and 100%	0.45	5.6	2.84	Fresh, compressive strength and splitting tensile strength
14	Mortar	River Sand	2.84	II	OPC - 53	0%, 50% and 100%	0.50 and 0.55	5.6	2.84	Compressive strength for 1:2, 1:3 and 1:6
15	Concrete	River Sand	2.787		OPC- 53	0%, 30%, 50%, 70% and 100%	0.58	0.60	2.90	Slump, compressive strength
16	Concrete – M20 & M30	River Sand	2.52	II	OPC - 43	0%, 20%, 40%, 60% and 100%	0.5 & 0.45	2.26	2.75	Slump, compaction factor, Vee-bee, Compressive strength, splitting tension strength, flexural strength & acid treatment
17	Concrete –M30	River Sand	2.59	-	PPC	0%, 30%, 40%, 60% and 80%	0.5 & 0.48	-	2.52	Compressive strength and splitting tensile strength
18	Concrete – M20	River Sand	2.5	II	OPC - 43	0%, 5%, 10%, 15%, 20%, and 25%	0.53	0.26	2.75	Compressive strength and splitting tensile strength
19	Concrete – M60	River Sand	2.65	II	OPC - 53	0%,20%, 40%, 60%, 80% and 100%	0.32	-	2.86	Compressive strength and structural behaviour of column
20	Concrete – M40	-	2.57	-	OPC and GPC	100%	0.35	-	-	Compressive strength, acid attack, sulphate attack and chloride attack.
21	Concrete – M60	River Sand	2.56	II	OPC -53 & 7.5% Silica fume	0%,10%, 20%, 30%, 40, 50%, 60% and 70%	0.32	-	3.10	Compressive strength, splitting tension strength and flexural strength
22	Concrete – M60	River Sand	2.65	II	OPC -53 & Silica fume	0%,20%, 40%, 60%, 80% and 100%	0.32	-	2.86	Compressive strength, splitting tension strength,SEM, EDS sorptivity and RCPT
23	Concrete –M30	River Sand	2.68	-	OPC – 43 & 1% Steel fiber	0%, 30%, 40%, 50% and 60%	-	7	5.2	Compressive strength, splitting tension strength and flexural strength
24	Concrete – M60	River Sand	2.78	II	OPC -53, Fly ash, Silica fume, Glass fibre, Polypropylene fibre &Recron 3s fibre	100%	0.3	-	-	Compressive strength, splitting tension strength, flexural strength and RCPT
25	Concrete – M40	River Sand	2.73	-	OPC -53, Fly ash and Silica fume	0%, 50% and 100%	0.28	-	4.66	Slump, and compressive strength

Continued on next page

Table 1 continued

Reference	Study area	MC	SG	Z	TB	RP	w/c	WA	FM	Analysis
26	Concrete – M20 & M30	River Sand	2.57	II	OPC – 43	0%, 20%, 40%, 60% , 80% and 100%	0.5 and 0.45	2.26	2.75	Slump, compressive strength, splitting tension strength, flexural strength & acid treatment
27	Concrete – M60	River Sand	-	II	OPC -53, Fly ash and Silica fume	100%	-	-	2.4 to 3.1	Slump, compressive strength and splitting tensile strength
28	SCC -M35	-	2.65	-	OPC -53	100%	0.54	-	3.12	Sulphate and Chloride immersed strength

Note: MC - Materials used for Comparison, SG - Specific Gravity of FeCr or Msand, Z - Zone of grained sand, TB - Types of Binder, RP - Replacement Percentage of FeCr slag or Msand, w/c - Water Cement ratio, WA – Water Absorption(%) and FM – Finess Modulus.

OPC (Ordinary Portland Cement) with 7.5% weight of silica fume is studied with 0% to 70% replacement of virgin sand with Msand. Compressive strength, split tensile strength and flexural strength increases in a consistent manner up to 60% replacement in HPC cluster [21]. Mechanical performances like compressive, flexural strength, splitting tensile and Modulus of Elasticity are increased with 5% silica fume in a binder and 100% Msand in HPC matrix. Sorptivity and Rapid chloride penetration (RCPT) result of fully replaced Msand give better performance than all other mix. Msand from EDAX report shows rich presence of Silica and Aluminium which leads to earlier strength on the matrix, there by recommending fast track opening projects [22]. Msand in concrete gives a better strength in 50% replacement with river sand, cost of Msand is less than traditional sand [23]. OPC -53 incorporates different minerals such as Fly ash, Glass fibre, Silica fume, Polypropylene fibre andRecron 3s fibre with 100% of Msandto form HSC recipe; moreover, Splitting tensile strength and compressive strength increases respectively. The RCPT value of Msand shows that chloride ions are high. For HSC fly ash and Recron 3s fibre are recommended for 100% Msand replacement [24]. River sand when replaced with 50% and 100% weight of Msand, compressive strength increases with 5.7% and 7.03% than control mix. Author concludes and recommends that fully river sand can supplant Msand in concrete cluster [25]. Msand with 60% weight of river sand shows a higher compressive strength than other mix, where workability also increases slightly. HCl immersed strength decreases slightly than control for both M30 and M20 concrete. Msand in 60% of river sand weight in concrete matrix is recommended [26]. Fully replaced Msandalong with OPC 53, Fly ash and Silica fume works as a binder. Moreover, HSC mineral admixture with Msand shows a good result on compressive and splitting tensile strength [27]. Msand (100%) satisfies filling ability of the fresh SCC as per European standard. Concrete immersed in Sulphate and chloride solutions, showed an increased immersed strength after 28days but thereafter decreased [28]. According to author, 20% of FS are relative to control matrix in both destructive and non-destructive behaviour. Due to clay, wood flour and debris in FS, leads to decrease in strength if the use of FS is above 20% in the production of concrete [29]. By increasing the percentage of copper slag in concrete, there is a decrease in compressive strength of concrete. This is due to the existence of excessive water, which improves the workability of the higher percentage of replacement of copper slag as fine aggregate in concrete. The retained excess water does not participate in the hydration process and forms internal voids, which weakens the bond between the interiors of concrete and reduces its strength and further leads to a brittle failure in concrete [30].

Figure 1 represents the particle size distribution and D_{50} size of particles are marked on the graph between grained Msand and FeCr slag. Except [12], all other curve falls within zone II. Based on well grading it also contributes to the better strength and durability property of the concrete mixture due to a proper S-curve formation. The strength parameters are discussed by using Percentage Difference formula from the equation (1).

$$\text{Potential Difference } (\%) = \frac{|v_1 - v_2|}{\frac{|v_1 + v_2|}{2}} \times 100 \quad (1)$$

Where,

V_1 is the reference strength

V_2 is the obtained strength

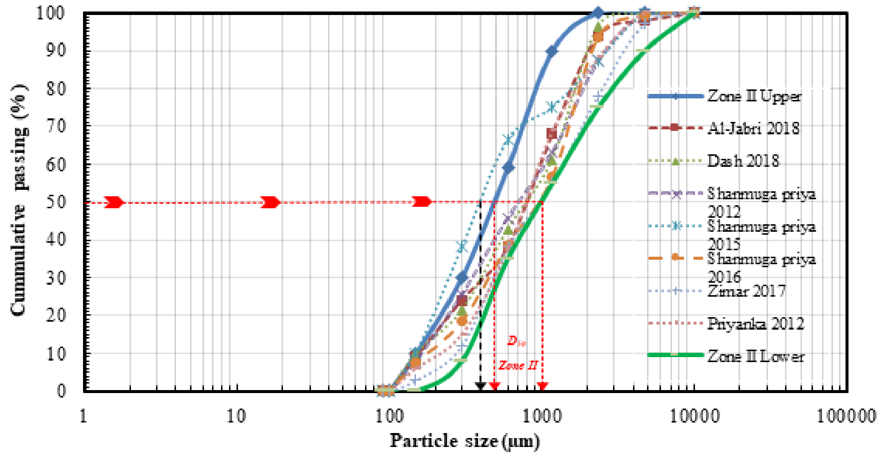


Fig 1. Particle size distribution curve

3 Compressive strength

3.1 FeCr Slag - Compressive strength summary

Compressive strength of FeCr slag in concrete are represented in a graphical format Figure 2 . According to author FeCr slag was replaced instead of natural sand by weight of 20%, 40% and 60% respectively. These works were incorporated with three various cement like OPC, PPC and PSC. Further in OPC matrix, strength percentage difference decreases to 3.67%, 2.99% and 1.32% than river sand matrix. In PPC 0.33%, 1.32% and 0.99% was decreased respectively. Where PSC matrix has lower percentage difference in compression of 0.99%, 0.66% and 1.33% respectively than the reference mix. This concluded that FeCr with PSC nearly matches with the river sand result. Slags MgO immigrant in the concrete false set and reduces its earlier age crushing strength [2]. An experiment of FeCr slag as fine aggregate was supplants 10%, 20%, 30%, 40% and 50% respectively in concrete. Moreover, 2.26%, 13.48%, 10.11%, 10.50% and 15.47% decreases its crushing percentage difference than control mix with complete river sand. MgO in FeCr slag slows the history of hydration at earlier ages [3]. By replacement of FeCr slag in concrete matrix (10%, 20%, 30% and 40%). However, 10.56%, 10.56%, and 8.38% decreases its percentage difference, up to 30% replacement. Where, there is a sudden increase in 40% replacement is 30.74% of the increase in percentage difference than reference mix of 100% river sand [4].

3.2 Manufactured sand - Compressive strength summary

In [12] studied the OPC and Silica fume (1.5%, 2.5% & 5%) as binder with 10%, 30% and 50% replacement of Msand instead of river sand. For 10% replacement, 2.5%SF and 5%SF increases its percentage difference up to 4.85% and 5.76% than 1.5%SF. Where, 30% of Msand replacement with 2.5% and 5% SF increases its percentage difference up to 6.15% and 6.89%, respectively. In 50% replacement of Msand, rises its percentage difference of 4.46% and 5.16% for 2.5%SF and 5%SF. Msand replaced in 20%, 40% and 60% instead of river sand. Moreover, the replacement percentage increases the percentage difference up to 3.38%, 3.76% and 11.86%, respectively than natural sand strength [13]. In [15] studied, Msand (30% and 50%) replacement for river sand in concrete. However, there is a 4.8% and 5.96% of increase in percentage difference. In [16] studied M20 substituted 20%, 40% and 60% of Msand instead of river sand. 7.04%, 9.68% and 18.18% increases its percentage difference than control strength. In M30 grade of 20%, 40% and 60% Msand is used in concrete for river sand. Moreover, 0.67%, 0.67% and 9.93% of percentage difference crosses higher than reference mix [16]. In water cement ratio (w/c)of 0.5, author substituted 20%, 40% and 60% of Msand in nominal river sand mix. For 20% replacement, percentage difference decreases up to 1.37% than nominal. And in 40% and 60%, replacement increases to 3.47% and 16.69% of percentage difference than 100% river sand compressive strength [17]. For w/c of 0.48, author supplants Msand in concrete in 20%, 40% and 60% by weight. 8.84% and 3.97% decreases its percentage difference for 20% and 40%. But in 60% replacement, 7.83% of the increase in the percentage difference than 0% of Msand mix crushing strength [17]. Msand replaced for natural fine aggregate. Author reports that with 10% and 20% of Msand, which increases its percentage difference of compressive strength up to 3.08% and 2.02% respectively [18]. Msand of 20%, 40% and 60% substituted instead of river sand. Further, 0.49%, 3.59% and 4.73% increase of percentage difference than conventional

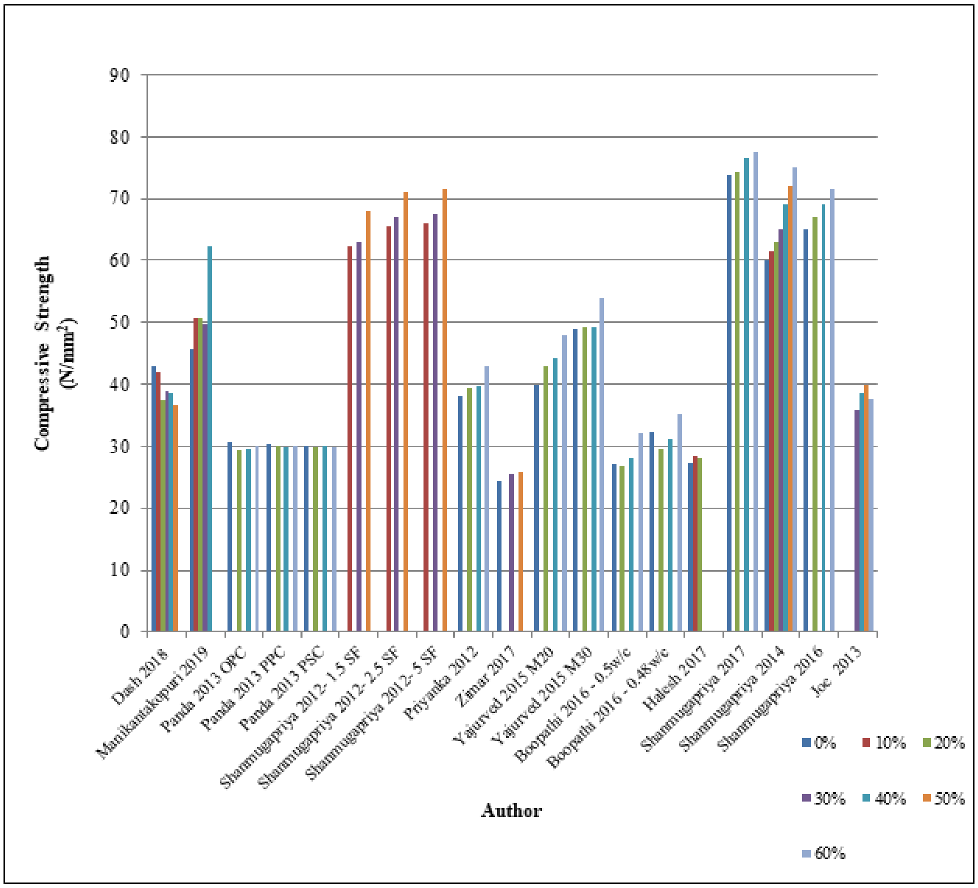


Fig 2. Compressive strength

sand strength. 100% replacement also gives a better result than river sand strength [19]. OPC with 7.5% Silica fume binder is referenced with river sand in comparison with (10%, 20%, 30%, 40%, 50% & 60%) of Msand. Compressive strength increases its percentage difference of reference mix and other replacements by 2.46%, 4.87, 8%, 13.95%, 18.18% and 22.22%, respectively [21]. OPC grade 53 and Silica fume as a binder with natural fine aggregate replaced with 20%,40%, and 60% of Msand by weight. Moreover, there is a 3.03%, 5.97% and 9.52% of increase in percentage difference than control mix of river sand [22]. OPC grade 43 and 1% Steel fiber as binder with 30%, 40%, 50% and 60% replacement of Msandandfound that 50% replacement gives better experimental results than other replacements. 50% Msand mix gives 10.47% increase in the percentage difference than 30% replacement [23].

4 Splitting tensile strength

4.1 FeCr slag splitting tensile summary

By replacing FeCr slag (10%, 20%, 30%, 40% & 50%) with river sand. Experimental results of splitting tension showed a decreased in percentage difference of 1.96%, 6%, 0.55%, 5.42% and 13.33%respectively than 100% of river sand strength [3,5]. Author studied by substituting FeCr (10%, 20%, 30% & 40%) with weight of river sand. The tension results by splitting cylinder displays an increase in the percentage difference of 10.18%, 15.78, 16.99 and 31.08%respectively than control splitting strength [4,8]. Figure 3 concludes a splitting tensile strength of past researches on FeCr slag and Msand replacement.

4.2 Manufactured sand splitting tensile summary

A particular work by replacing 20%, 40% and 60% of Msand by fine aggregate. Moreover, the splitting tensile strength behaviours are better than control mix. There is a 9.02%, 9.92% and 10.82% increase in percentage difference, respectively [13]. In M20 grade

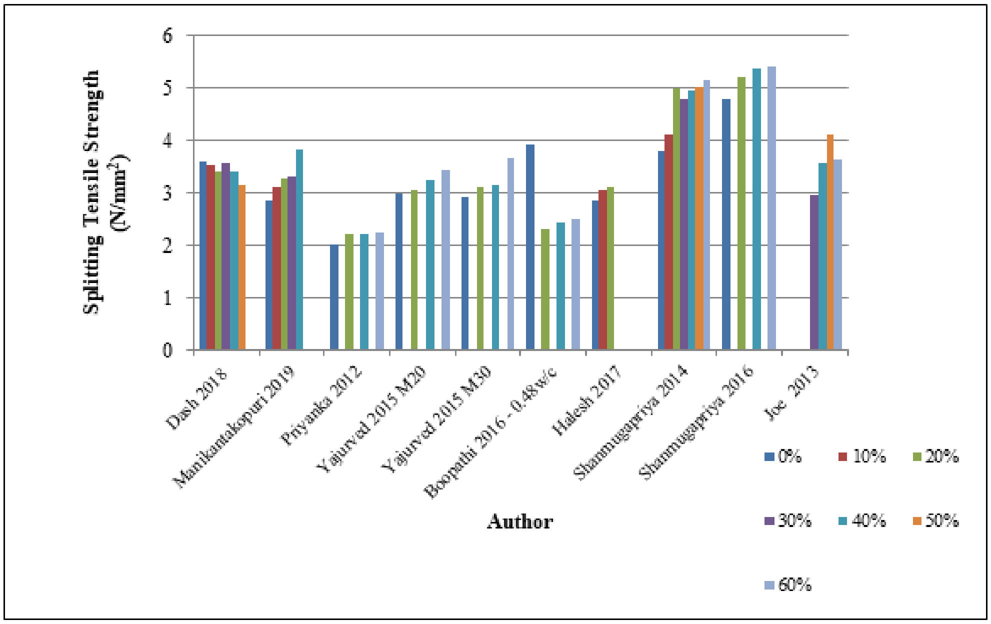


Fig 3. SplittingTensile Strength

by replacing 20%, 40% and 60% of Msand by weight as fine aggregate. Experimental results shows an increase in the percentage difference such as 5.96%, 6.91% and 22.42% than reference river sand strength on 28th day. Further in M30 grade substituted Msand (20%, 40% and 60%) by river sand. It produced 2.32%, 9% and 14.66% of increase in percentage difference than control splitting strength after 28th day of curing [16]. For w/c of 0.48, Msandreplaced (20%, 40% and 60%) instead of natural sand. Outcomes with decrease percentage difference than control strength 51.04%, 45.91% and 44.37% splitting tension strength respectively [17]. Author replaced 10% and 20% weight of Msand in concrete than river sand. However, splitting tensile strength of cylinder results shows an increases in the percentage difference by 6.77% and 8.40% than reference splitting strength [18]. Portland cement with 7.5% Silica fume as a Cementitious material along 10%, 20%, 30%, 40%, 50% and 60% of weighted Msand instead of river sand. Laboratory results of splitting tensile strength showed an increase in the percentage difference by 8.32%, 27.27%, 23.25%, 26.28%, 27.66% and 30.16% respectively in comparison with control concrete splitting tension strength [21]. OPC grade 53 and Silica fume as binder with Msand in different weights(20%, 40%, and 60%) as a replacement of river sand. Author concludes on splitting tensile strength that on 28thdaycuring.percentage difference increases to 8.78%, 11.78% and 12.15% than nominal strength [22]. Portland cement of grade 43 and 1% Steel fibre as binder along with 30%, 40%, 50% and 60% of Msand by weight incomparison with river sand. In addition of 50% Msand gives better splitting tensile results than other mix [23].

5 Flexural strength

5.1 FeCr slag flexural summary

Flexural study by replacing FeCrslag (10%, 20%, 30%, 40% & 50%) instead of river sand. Although, there is a decrease in the percentage difference by 3.05%, 6.20%, 12.08, 8.52% and 10.16% respectively while comparing the control flexural strength [3] FeCr slag (10%, 20%, 30% & 40%) as fine aggregate in concrete instead of river sand was conducted. Flexural strength in comparison with control mix increases the percentage difference 0.03%, 1.48%, 3.48% and 5.22% respectively [4].From Figure 4 the flexural strength of FeCr slag and Msand replacement are represented.

5.2 Manufactured sand flexural summary

Portland cement and Silica fume (1.5%, 2.5% & 5%) used as binder with 10%, 30% and 50% replacement of Msand instead of natural river sand. However, 10% replacement with 2.5%SF decreases the percentage difference up to 1.37% and in the same sand proportion with 5%, SF increases the flexural the percentage difference by 8.14% than 1.5% SF flexural strength. In 30%

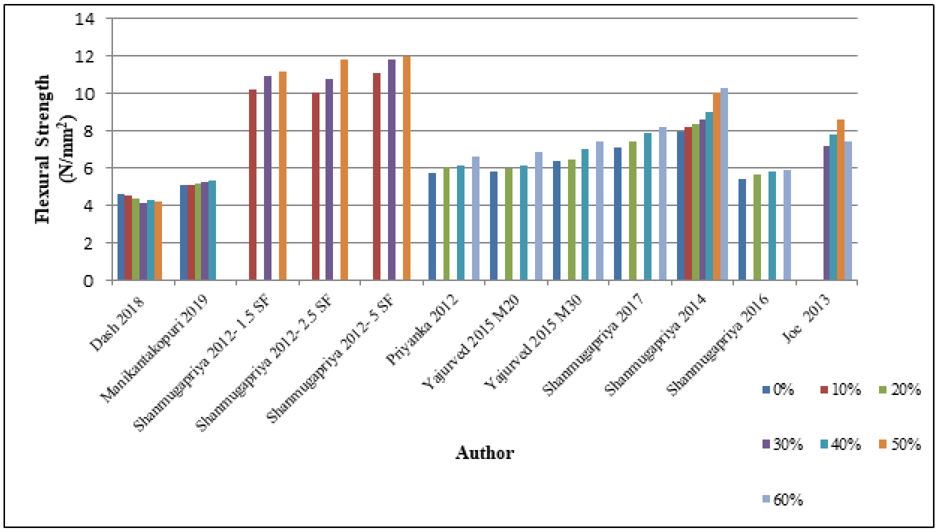
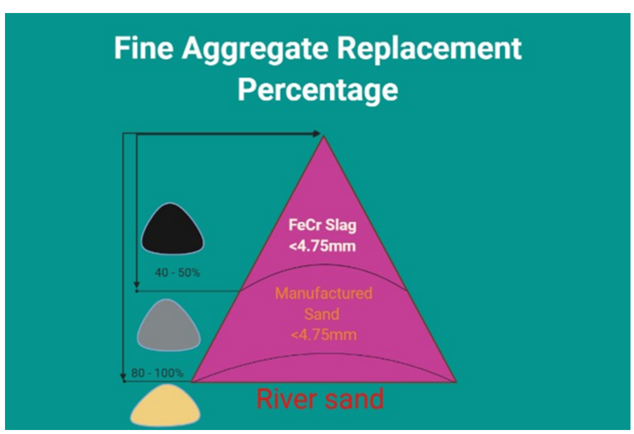


Fig 4. Flexural strength

replacement flexural strength of 2.5%SF decreases its percentage difference up to 1.83% and in 5%SF increases its percentage difference by 7.29% than 1.5%SF flexural behaviour. By 50% replacement 2.5% and 5%SF increases its percentage difference to 5.21% and 6.89%, respectively in comparison with 1.5%SF [12]. Msand (20%, 40% and 60%) replaced with river sand. Further, percentage increases by 4.58%, 6.72 and 13.61% with regard to control flexural strength on 28 days of curing [13].

In M20 grade concrete 20%,40% and 60% Msand is replaced instead of river sand. Moreover, there is also 2.89%, 6.04 and 16.50% increase in percentage difference respectively. Moreover, M30 grade supplants 20%,40% and 60% Msand to natural river sand. Laboratory Flexural results showed an increases in percentage difference by 0.93%, 9.25% and 14.64%, respectively in comparison with control concrete flexural strength [16]. Msand of 20%, 40% and 60% replaced by weight with river sand as fine aggregate. The study shows that the percentage difference increases than control flexural strength by 4.26%, 10.63% and 14.22%, respectively. Author also report 100% replacement of Msand also gives the percentage difference increase than control strength [19]. Silica fume (0.5%) with OPC as cement composites and Msand (10%, 20%, 30%, 40%, 50% & 60%) supplants instead of river sand although, percentage difference increases by 2.46%, 4.87%, 10.65%, 11.76%, 15.02% and 23.20% respectively on flexural behaviour in concrete [21]. OPC53 grade and Silica fume as binder with 20%, 40% and 60% Msand used instead of river sand. There is a 5.42%, 7.68% and 9.21% of the percentage difference increase in comparison with the control concrete flexural strength [22].Portland cement and1% Steel fiber used as binder with 30%, 40%, 50% and 60% of Msand by weight of river sand are discussed. Moreover, 50% of Msand gives better flexural strength results than all other results [23].

Graphical Abstract



Graphical abstract clearly states that the recommended percentage of FeCr slag and Manufactured sand replacement instead of river sand. FeCr slag can be replaced upto 40% to 50% by weight and Msand can be supplants 80% to 100% of virgin sand.

Colour of FeCr slag was nigritude black due to some amount of chromium and iron, Msand was grey which represented in image.

6 Conclusion

6.1 FeCr Slag

- FeCr slag has leaching characterised metal CrVI from industrial waste slag, so before using it one has to characterise its physical and chemical properties.
- FeCr Slag as fine aggregate is slow reactive due to MgO and reduces its earlier strength. At later ages it shows a good result than ordinary sand strength.
- The shape and texture of FeCr slag support a matrix to give a brittle nature and it also consumes less amount of water though slag is porous in nature..
- Higher thermal conductivity of slag leads to the reduction of the thermal stress on matrix.
- The conclusion of the study emphasizes that FeCr slag sand from 40% to 50% by weight replacement shows better strength performance compared to river sand. 50% of Msand gives better flexural strength results than all the other replacement.

6.2 Manufactured Sand

- Manufactured sand gives high early strength due to Al_2O_3 and SiO_2 ingredients. Zone II of the crushed Msand is a better one than all other zone sands.
- Msand is far better than FeCr Slag as aggregate, based on bonding (ITZ) between cement pastes and increases its mechanical test result values.
- The pore structure of Msand is much lesser than FeCr slag composite. And Msand can be 80 - 100% replaceable based on these literature studies (vide Graphical Abstract).

A brief study concludes and recommends based on delay in the earlier strength of FeCr slag matrix and greater earlier strength of Msand matrix. But both FeCr and Msand can be replaceable in concrete and mortar. FeCr slag can be suggested for use in small concrete blocks, concrete wall panels, and where there is a delay in the removal of shuttering and framework. Manufactured sand can be suggested for all types of concrete like Fast track opening projects, metro works, bridges, and skyscrapers.

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