All-In-One about a Momentous Review Study on Manufactured-Sand as Fine Aggregate in Concretes

Faizan Ahmad Wani, R. Ramasubramani

Abstract: Natural river sand (NRS) has been in use as fine aggregate in various types of concrete and mortar works and as the demand for concrete based products is rising due to the exponential infrastructure growth globally it is needed that more fine aggregate be produced, causing detrimental effects on the environment because of the excessive sand quarrying to produce the required quantum. The environmental concern has forced various State Governments to impose restrictions on NRS quarrying; further the excessive, illegal and seasonal NRS quarrying has caused a steep hike in NRS prices. Researchers have been taking efforts to find an alternative to NRS as a replacement of fine aggregate in conventional concrete and M-sand (Manufactured sand) has surfaced as a viable alternative. The parent source of M-sand is the abundant lithological reserve (rock) of the earth's crust and it is produced by crushing these rocks as per a grade of requirement to act as a partial or full replacement of NRS in concrete and mortar works. M-sand production process gives control over the quality, quantity, form, quarrying and crushing methods, it also checks onto the unwanted organic and soluble compounds, which are generally expected to be along with NRS, thus helping to maintain end product quality. M-sand characteristic properties have significant effects on compressive strength, flexural strength, impact resistance, abrasion resistance, permeability, workability etc. all these have been discussed in this paper. One of the major issues with production of M-sand was the excess of fines produced, which was disposed off at high prices initially but now with advancements in M-sand technology the fines have been used as supplementary cementitious material in M-sand concrete and mortar works. This study delineates the effects M-sand and fines on concrete, various special concretes and on mortars. Their performance in association to various parameters of strength and other durability properties is presented in a detailed manner.

Keywords: Concrete, Fines, M-Sand, Natural river sand, Replacement of fine aggregate.

Abbreviations: NRS – Natural river sand
M-sand – Manufactured sand (crushed rock sand)
SCC – Self compacting concrete
PCC – Pavement cement concrete

I. INTRODUCTION

M-sand (as per Indian standards) is defined as the fine aggregate produced by crushing hard rock such that most of the crushed material passes through the 4.75mm IS sieve and contains only so much of coarser material as permitted by IS size and grading of aggregate [1].Manufactured-sand also called as M-sand (as designated in this paper), Crushed-rock-sand and manufactured-rock-sand has surfaced as a viable alternative to the Natural-river-sand [2].

Rapid growth of infrastructure globally has resulted into immense pressure on concrete industry to produce large quantum of concrete to meet the demand and the resulting excessive mining has caused detrimental effects on the environment like deterioration of river ecology, loss of water retaining sand strata, bank slides due to excessive deepening of river, disturbance in aquatic life and agricultural sector because of lowering of water table several state governments have imposed restrictions on quarrying of sand, further the excessive and season bound mining has caused a lack or total unavailability of NRS causing hike of prices of NRS in many regions of the globe, the hike of prices is further intensified due to the additional cost of transportation required to take the NRS from mining site (the river) to the end user [3]–[5]. Production of M-sand requires more energy than that of NRS but the decreased requirement of transport and the efficiency of production with the technological advancements make M-sand more favorable [6]. M-sand is being produced by variety of methods of crushing including cone crushers, impact crushers, roll crushers and rod mills which have a direct influence on grading, shape, surface texture and even integrity of the product [6], [7].Production and use of M-sand has come up with many advantages such as the choice of the parent rock to be crushed which gives control over the quality, quantity, type, form, porosity, absorptivity, quarrying and crushing methods thus helping in prediction of end product quality and reduction of the production cost. The production process of M-sand as compared to NRS provides a check over the unwanted organic and soluble compounds which cause alteration of strength and setting time and the avoidance of such impurities by proper selection of source increases the quality [6].

M-sand is put to work in concrete as a partial or full replacement of NRS fine aggregate. M-sand has been used in a variety of concrete works in highways, dam and bridges projects and all types of commercial construction works and concrete products including pre-cast elements, pipes and concrete blocks. With M-sand as fine aggregate the Pune – Mumbai express highway, one of the biggest projects undertaken in India, has been completed wherein 20,00,000 m^3 of concrete used [8]. A major environmental issue due to production process of M-sand, M-sand majorly being produced from hard lithological sources: Granite, Limestone and quarts, is the excess fines produced during crushing of the parent rock which were disposed off at high cost but now have been put to use as supplementary cementitious material in M-sand concrete and mortar works [6], [9].

Revised Manuscript Received on May 06, 2019

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II. Properties of M-sand

A. Chemical Properties

Chemical properties and components of M-sand depend on the parent source of the sand, XRD diffraction studies have shown that M-sands contain typical rock forming minerals like quartz, feldspar and mica group of minerals the chemical composition of M-sands are comparable to that of NRS [10]. Figure A shows the chemical components of 'Meta sand stone M-sand' and NRS [11].

B. Physical Properties

M-sand quality parameters are related to the parent source (particle shape and texture) and the production process (stone powder content, clay lump content and gradation). These properties in general differ from that of NRS. Upon visual inspection M-sand is observed to have more angular but smooth surface as compared to NRS having rounded and irregular surface (caused due to weathering overtime) [12]. The particle shape determination when done on basis of length to width ratio (L/W) and roundness showed that M-sands have higher L/W and roundness values also it was observed that M-sands contain more platy, elongated and angular particles [7]. Laser scans showed an unconventional result that M-sand surface roughness is less than that of NRS as M-sand surface is a crushing fracture surface which exposes new crystal faces which at micro scale are smooth where as for NRS the overall surface appears to be smooth but at micro scale level its surface showed erosion caused due to various weathering agents [12].

The simple system shown in Table B.1 and B. 2 (Table 6 & 7 in IS : 383 – 1970) has, therefore, been devised and is put forward in the hope that it will facilitate defining the essential features of both particle shape and surface characteristics of aggregates [1].

M-sand, due to the crushing process, has 10% to 20% fines, called dust or stone powder, by weight (fines being defined as particles passing through 75 µm sieve it is inevitable to yield dust content during crushing process [1], [11], [12]. These fines effect the porosity, chloride ion permeability, freeze thaw resistance and water reducer content of concrete [12], [13]. The size reduction of rocks (crushing) to produce M-sand is commonly done by Cone, Impact, and vertical shaft impact crushers these crushing processes have direct influence upon concrete performance as these determine the grading, shape, surface texture and the integrity of the manufactured aggregate also the crushing process influences the amount of fines (dust) produced. The production of fines can be controlled to some extent by setting appropriate crushing conditions and size classifications thus being effective in reaching the grading curves and particle shapes meeting the desired specification [14].

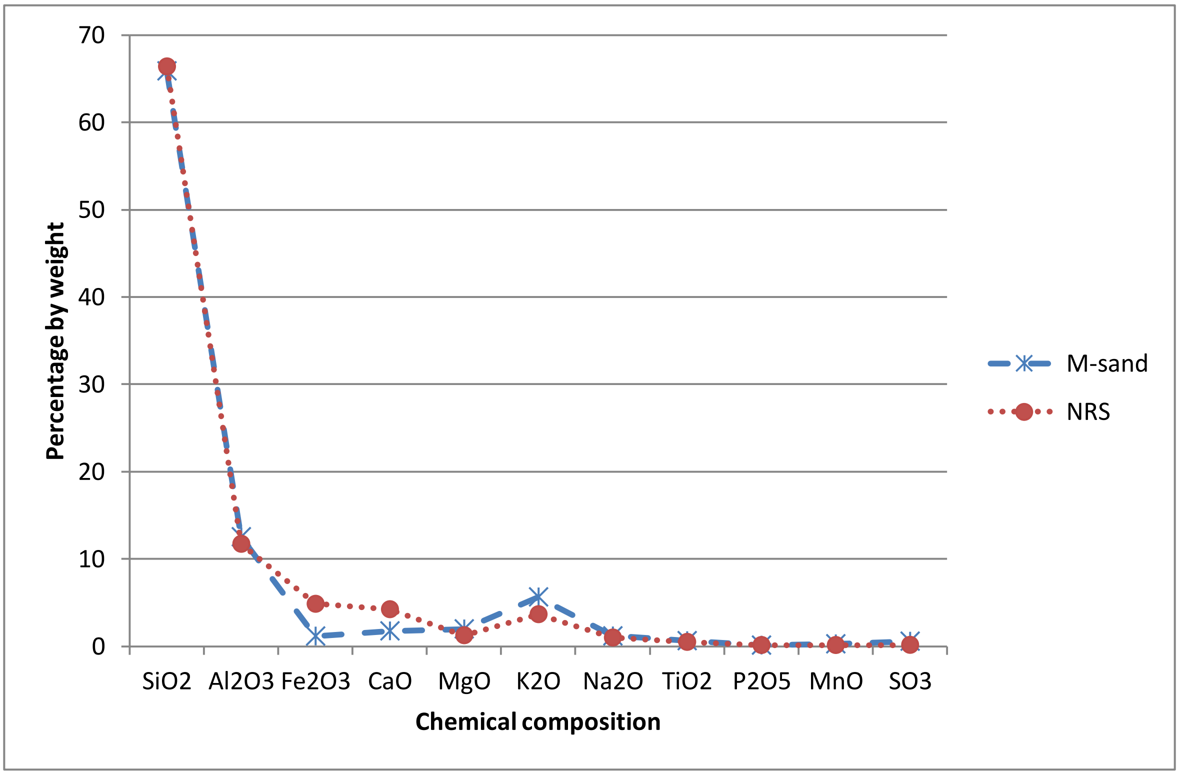

Figure A Comparison of chemical composition of M-sand and NRS (Percentage by weight) [11]

Classification	**Description**	**Illustration Of Characteristic Specimens**	**Example**
1	2	3	4
Rounded	Fully water worn or completely shaped by attrition	Fig. i	River or seashore gravels; desert, seashore and windblown sands
Irregularly or partly rounded	Naturally irregular, or partly shaped by attrition, and having round edges	Fig. ii	Pit sands and gravels; land or dug flints; cuboid rock
Angular	Possessing well-defined edges formed at the inter-section of roughly planar faces	Fig. iii	Crushed rocks of all types; tullus; screes
Flaky	Material, usually angular, of which the thickness is small relatively to width and/or length	Fig. iv	Laminated rocks

Table B.1 **Particle Shape** (Table 6 in IS: 383 – 1970; clause C-3.2) [1]

Particle shape images taken from IS: 383 – 1970

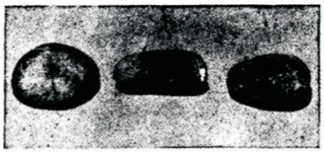

Fig. i

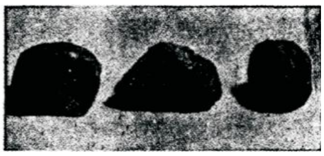

Fig. ii

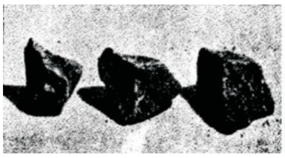

Fig. iii

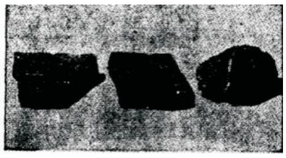

Fig. iv

Table B.2 **SURFACE CHARACTERISTICS OF AGGREGATES**

(Table 7 in IS: 383 – 1970; clause C-3.2) [1]

Group	**Surface Texture**	**Example**
1	Glassy	Black flint
2	Smooth	Chert, slate, marble, some rhyolite
3	Granular	Sandstone, oolites
4	Crystalline	Fine: Basalt, trachyte, keratophyre Medium: Dolerite, granophyres, granulite, microgranulite, some limestones, many dolomites Coarse: Gabbto, gneiss, granodiorite, syenite
5	Honey combed and porous	Scoriae, pumice, trass

III. EFFECTS OF PROPERTIES OF M-SAND ON CONCRETE

A. *Effect of Angular Nature of M-sand Particles on Concrete*

The angular nature of M-sand results into higher void content in concrete thus increasing the water demand for a same slump as that of NRS, the voidage also increase the quantity of cement paste

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needed to fill the voids but the angular nature increases the friction force among the paste embedded particles [12]. It was concluded that though M-sands require higher water reducer dosage M-sand concrete with same water to binder ratio has higher strength than that of NRS concrete [12].Based upon analysis of various samples of M-sands with different roughness and particle shape it was concluded that in practice M-sand particle shape and micro roughness has influence on behavior of concrete but the gradation, fines content and clay lump content have more significant influence on behavior and properties of concrete [12].

B. Effect of M-sand on Strength of Concrete

Compression tests were done on high performance concrete, in which different sands were used, at age of 7 and 28 and 60 days and it was observed that strength of M-sand concrete was more than that of NRS concrete implying that micro roughness (characteristic of NRS) has little effect on strength of concrete. It was concluded that production related parameters of M-sand have more influence significance on concrete when M-sand is used as compared to the resource parameters of M-sand thus M-sand can be a high quality sand comparable to NRS when produced with qualified process [12].

C. Effect of Fines on Concrete

Fines (dust) present along with M-sand are considered as deleterious substance (when in excess) thus the ASTM C 33 limits the amount of fines present to 3% for concretes subjected to abrasion and 5% for other concretes, this increase is due to experimental evidence that amounts greater than these limiting values might not actually be harmful. In the same regard British-Standards allow up to 15% of dust content [15].

i. Effect of Fines on Workability of Concrete

The water demand for a constant flow increases as the amount of fines increases; this is attributed to the larger surface areas of fines (to be wetted). It was observed that as fines content increased more than 10% the water demand increased sharply [15]. The slump also decreased with increasing amount of fines due o the same reason of greater surface areas to be wetted further implying that as fines increase at a qualified water to cement ratio the workability decreases but upon further investigations it was found out that some amount of dust content contributed to increase the fluidity of mortar by filling into the gaps of aggregate thus increasing the slump content and the workability, this content was found out to be 7.5% by Weiguo Shen et al. 2018 [11] and any deviation from this value resulted to decrease of slump. These fines also decreased the air content of concrete upon increase [11], [15], [16]. Similar results were obtained by Xinxin Ding et al. 2016 [17] wherein stone powder content of 9% was concluded to be the best for workability of concrete as it increased the cohesiveness of fresh concrete.

ii. Effect of Fines on Permeability and Porosity of Concrete

At equal fines content particle shape has no significant influence on permeability of concrete as was concluded by similar values of permeability of different samples of M-sand with different particle shape, further, upon the chloride ion permeability the influence of gradation is little [11]. The dust content has remarkable influence on porosity of concrete in addition the irregular shape of M-sand enhances the structure of cement paste thus reducing the porosity of concrete [11]. As the dust content increases the coefficient of permeability decreases. Permeability tests on 75x75x150 mm prisms showed that the maximum value of permeability ‘K’ was 6.59x10-10 cm/s for 0% fines and the minimum value was recorded as 1.93x10-10 cm/s for a fines content of 30% this reduction in permeability with increasing fines content is due to blockage of passages connecting the water pores and capillaries by the fines [16].

iii. Effect of Fines on Strength of Concrete

The compressive strength tested as per BS 1881:1970 were performed on samples of M-sand concrete with varying fines content, it was observed that strength was maximum at age of 7 and 28 days when fines content was equal to 10% all other cases showed lesser strength. This was attributed to the fact that lesser amount of fines than 10% couldn’t fill all voids thus generating cavities within the structure of concrete on the other hand higher amount of fines than 10% the qualified cement paste was not sufficient enough to coat all the aggregate materials of the concrete [16]. It was found out by Weiguo Shen et al. 2018 [11] that the maximum strength of concrete was achieved at a fines content of 7.5% as this amount was sufficient to increase fluidity of cement slurry thus giving a more compact concrete structure [11].

iv. Effect of Fines on Flexural Strength of Concrete

Flexural strength was tested as per BS: 1881: part 4 : 1970. Maximum flexural strength at 7 and 28 days, being 3.09 MPa& 4.32 MPa respectively, was attained for a dust content of 10%. Similar arguments of cavity filling an decrease in voidage as given in case of compressive strength are applicable here [16].

v. Effect of Fines on Impact Resistance of Concrete

It was observed by Tahir Celik et al. 1996 [16] that at 5% of fines content the impact resistance of concrete was higher that other cases, the 150 mm diameter and 60 mm height cylindrical specimens took a maximum of 81 blows for the case of 5% fines and the number of blows decreased to 33 in case of 30% fines [16].

vi. Effect of Fines on Drying Shrinkage of Concrete

As investigated by Tahir Celik et al. 1996 [16] the drying shrinkage increased for a fines content of 0% to 10% and for fines content greater than 10% drying shrinkage decreased. At 10% fines content highest compressive strength was attained with a high value of drying shrinkage but as fines increased drying shrinkage increase but the compressive strength decreased [16].

D. Effect of M-sand on Freeze-thaw Resistance of Concrete

Upon testing M-sand and NRS concrete with same gradation and powder content for freeze-thaw resistance it was found that M-sand concrete sample was destroyed after 155 cycles and

NRS concrete at 135 cycles suggesting that M-sand concrete has higher freeze-thaw resistance attributed to the angular shape of M-sand which plays an important role in combination of cement paste and aggregate [11].

E. Effect of partial replacement of NRS by M-sand on concrete

Tests were done on concrete with 50% NRS and 50% M-sand as fine aggregate. According to the test results the concrete with mixture (50/50) of M-sand and NRS as fine aggregate showed maximum strength at all water : Binder ratios [17].

F. Effects of Properties of M-sand on Mortars

i. Effect of M-sand on Strength of Mortars

M-sand and NRS Mortars (1:4 and 1:6) were assessed as per IS 2250 code for compressive strengths at 85% and 100% flow Figure a. gives comparative data for these tests [10], [18]. The results indicate that M-sand mortars show higher strength in both cases of flow [10].

ii. Effect of M-sand Properties on Water Retentivity of Mortars

Water retentivity is defined as the ability of mortars to retain water against the sucking action of external agencies when in contact like bricks and blocks. Mortar has cementitious components which need water for proper hydration and strength development; if the amount of water loss is high it will lead to lower water : cement ration and improper hydration thus will affect the mortar characteristics and also the bond development. Tests done as per IS-2250 code guidelines showed that the use of M-sand in mortars resulted into improved water retentivity. Figure b. shows the comparative data of water retentivity of NRS mortar and M-sand mortar [10], [18].

IV. EFFECT OF M-SAND FINES ON MORTARS

A. Effect of M-sand fines on strength of mortars

Tests done on cement mortars (1:3) casted as per ISO standards showed that maximum strength was shown by the mortar sample with 5% to 10% fines content [15].

B. Effect of M-sand fines on workability of mortars

Tests done by V.L. Bonavetti et al. 1994 [15] showed that as the content of fines increased the water demand for a constant flow increased suggesting that the workability of mortars decreased, this was attributed to high surface are of fines (dust) to be wetted [15].

C. Effect of M-sand fines on air content of mortars

The air content of mortars decreased as the fines content increased, due to the filling of cavities of the mortar, as compared to the reference mortar series produced with no fine content [15].

D. Effect of M-sand fines on strength of mortars

Mortar without any fines at a constant flow was used as reference and mortars containing fines were tested by V.L. Bonavetti et al. 1994 [15], the result of these tests on 40x40x160 mm prisms of mortar casted as per ISO standards when compared to that of reference mortar showed that in general the strength of mortar with fines was always higher, this may be attributed to the fact that the voids of mortar are filled by the fines thus decreasing the cavities within the mortar leading to increase in strength [15].

E. Effect of M-sand fines on flexural strength of mortars

Tests on 40x40x160 mm prisms of mortar casted as per ISO standards showed that fines increased the flexural strength of mortars in all cases and the effect of increase in strength was more pronounced at an early age, after the period of 28 days the increase in strength was similar regardless of the type and quantity of fines [15].

F. Effect of M-sand fines on drying shrinkage of mortars

Tests done on 25x25x285 mm mortar prisms showed that the incorporation of fines in mortar always resulted to a higher drying shrinkage, this was attributed to the fact that fines increased the water demand thus increasing the content of water available for loss as capillary water during the shrinkage [15].

G. Effect of M-sand fines (limestone fines) on sulphate resistance of mortars

Tests done on mortars with water to cement ratio 0.5 after 10 months of sulphate attacking showed that the attacks decreased the flexural strength and compressive strength significantly but the results did indicate that the incorporation of fines (Limestone fines) improved the sulphate resistance of mortars [13].

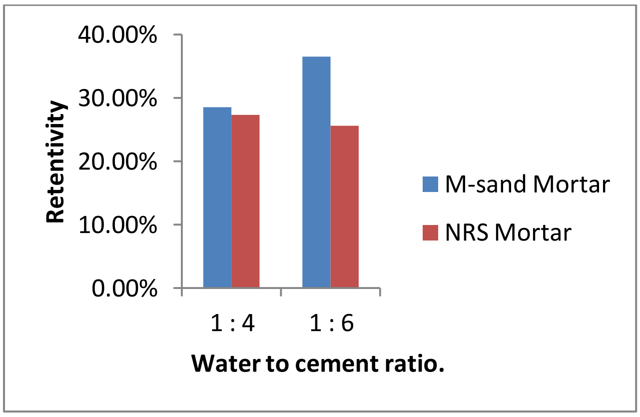

Fig b. Comparative Data of Water Retentivity of M-sand and NRS Mortar

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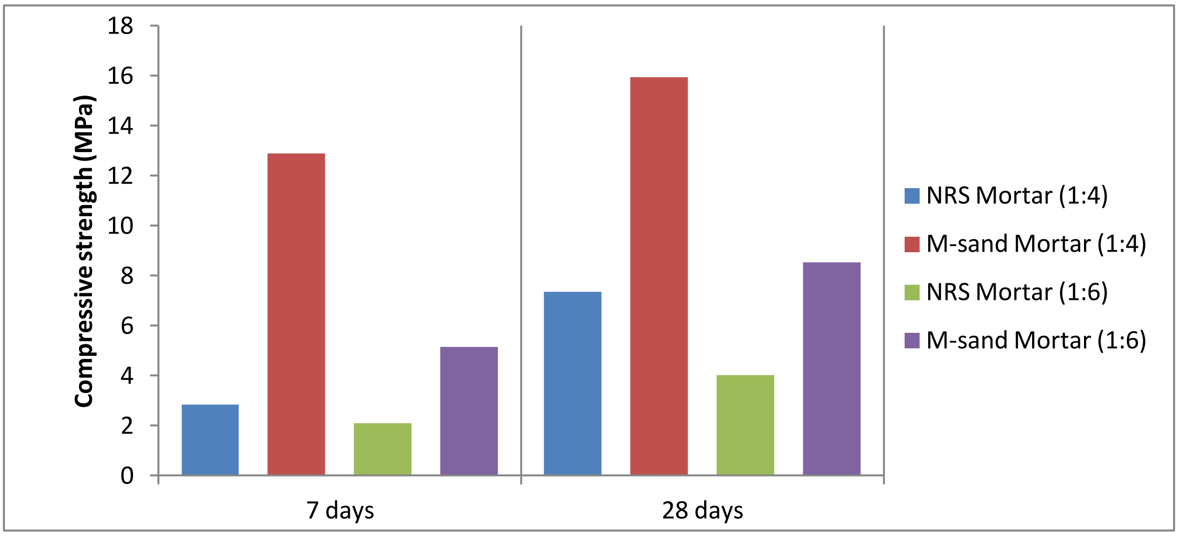

Fig a. Compressive strength of mortars at 85% flow

V. Effect of M-sand on special concretes

A. *SCC*

Self compacting concrete (SCC) is an innovative and highly flowable concrete that can be compacted to every corner without segregation purely by means of its own weight achieving full compaction even in presence of congested reinforcements without any need of mechanical vibration [19], [20]. The shape and texture of fine aggregate have high influence on SCC than that of coarse aggregate. Tests done on SCC made using M-sand from Granite source by impact crushing showed that cement paste volume has high influence on properties of fresh SCC for a specific combination of aggregates, it was found that to achieve a slump of 550mm a minimum of 160 L of water and 70-90 L of excess paste was required, per cubic meter of concrete, over and above the void content of the concrete [20].

B. *PCC*

M-sand and fines increase the compressive strength of PCC at a fines content of 10%, the micro fines also improve the packing density; increasing the paste matrix and ITZ (interfacial transition zone) density thus improving the pore structure in abrasion area resulting into higher abrasion resistance of M-sand PCC [21].

C. *High strength concretes*

Tests done on samples of high strength concrete having water : cement ratio 0.3 and cement content = 530kg/m^3 at a qualified slump with NRS and M-sand as fine aggregate showed that, both concretes have similar degree of hydration and have same mass of hydrated cement products at equivalent test stages however the M-sand high strength concrete developed higher strength as compared to that of NRS high strength concrete. This was attributed to the improved paste-fine aggregate interfacial transition zone due to the enhanced mechanical interlocking of manufactured fine aggregate (M-sand) due to angular geometry and rough texture [22].

VI. CONCLUSION

As the demand for concrete works and concrete based products increases the demand of fine aggregate, which form about 35% of concrete volume, also increases. To meet this demand it is needed that more amount of NRS be recovered from Rivers but a continuous quarrying and excessive use of NRS has depleted the NRS sources and led to a severe lack of NRS in many parts of the world, further the quarrying is seasonal thus leading to unavailability and high prices. The quarrying also causes detrimental effects to the environment, to counter such issues scientists have been taking effort in developing materials that can either partially or completely replace the NRS fine aggregate in concrete.

M-sand has surfaced as a feasible alternative to the NRS and from the review of literatures surveyed on M-sand and its role in concrete and other cement based products it can be concluded that M-sand is a viable replacement, either partial or full as per need and regulatory values, for the NRS fine aggregate. M-sand has opened ways to develop fine aggregate of specified properties. The source of M-sand is the rock reserve of the world; it is produced by crushing the rock by various processes to a specified zone of grading. The choice of parent rock for production of M-sand further gives control over the quality, quantity and other parameters of the fine aggregate. It has been found that the chemical and physical properties of M-sand are comparable to NRS. The physical properties of M-sand and NRS are different, on a visual scale M-sand is more angular but it has been established that it has more smooth surface texture on a micro-scale than that of NRS. It can be concluded that overall the properties of M-sand are comparable to natural river sand and the effects of M-sand on various properties of concrete and mortars are also comparable and positive especially the strength and resistance of the M-sand concretes and mortars. M-sand is produced by mechanical crushers. Parent rock material is fed to the crushers and a specific graded fine aggregate is obtained, but this process also generates a certain amount of fines upon crushing called the M-sand dust or M-sand fines.

These fines have marked effects on properties of concrete in which M-sand is used as M-sand is inevitably accompanied by fines, though fines can be washed off but that is not an economical process and is also hazardous to the environment because disposal concerns, thus researchers found out that the fines can be incorporated in the concrete itself as a supplementary cementitious material, based on review of literatures it can be concluded that a fines content of around 10% is the best optimized value when compressive strength, flexural strength, workability, freeze-thaw resistance, impact resistance and other properties of concretes, mortars and other cement based products are taken into account.
M-sand has been used as partial and full replacement of NRS in cement based products more research is being done in the field of finding alternatives to NRS. M-sand can be designated as one of the best viable alternatives to NRS as per the degree of advancements achieved as of now and with hope in advancement of technology to harness M-sand properties for more use to safeguard the future.

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