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Optimizing Blending of Manufactured Sand with Offshore Sand Based on Physical and Virtue Characteristics

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Authors' contributions

This work was carried out in collaboration among all authors. Authors AB, KMCK and SMAN designed the study, performed the statistical analysis and wrote the protocol. Author AB wrote the first draft of the manuscript. Authors KMCK and SMAN managed the analyses of the study. Author HMRP managed the literature searches. All authors read and approved the final manuscript.

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ABSTRACT

Usage of alternative fine aggregates in concrete and cement mortar has been gradually increasing by the construction industries around the world due to the escalated shortage in obtaining natural river sand. Manufactured sand and offshore sand can be considered as the principal alternatives which are consumed by most of the contractors for substituting river sand in the construction activities now. However, most of the above sand consumptions are done without deeply analyzing the conformity of the alternatives to concrete and cement mortar. The present study is executed to inspect the fitness of manufactured sand from two different high-grade metamorphic rocks, offshore sand, and blended sands of both manufactured sand types at 25%, 50% and 75% replacement levels with offshore sand to be practiced in concrete and cement mortar by scrutinizing physical properties and quality through series of characterizing experiments. Results

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reveal that blended sand with all replacement levels can be suitable with respect to particle characteristics such as angularity, surface texture and total specific surface. Regarding resultant particle size distribution, blended sands with 50% replacement level can be the optimum solution in reference to uniform gradation, the density of sand mix, and fineness. 50% and 75% contents of manufactured sand in combined sand types show higher loose and packing densities than river sand. Flowability under the gravity of blended sand types contain 50% to 75% of offshore sand are performed well contemplating different affecting parameters. However, increased manufactured sand content demands more water than river sand and offshore sand. Additionally, hazardous materials such as clay lumps and friable particles, fines and silt are identified within the permissible range based on the requirements by the standard available. Regarding all the above characteristics, blended sands contain two manufactured sand types with 50% replacement level with offshore sand can be suggested as the optimum substitution for river sand in terms of fresh and hardened state properties of concrete and cement mortar.

Keywords: River sand; M Sand; offshore sand; blended sand; fine aggregate.

ABBREVIATIONS

River sand (RS); Manufactured sand from Hornblende-Gneiss rock (MS(HG)); Manufactured sand from Charnockite rock (MS(CH)); Offshore sand (OS).

1. INTRODUCTION

Presently, the usage of fine aggregates has escalated with the increased construction industries all over the world. Fine aggregate is a salient constituent which is usually 35% to 45% by mass or volume of total aggregate content [1-3]. It highly controls the strength and workability by packing the voids between coarse aggregate particles and reduces cement requirements for the mixes. Natural river sand is the most common fine aggregate type that has been utilized in construction activities. RS is restricted from being extracted by the sand miners due to the surged environmental drawbacks [3-5]. Government sectors are imposing curtailments on RS mining activities, enhancing the demand for fine aggregate and leads the construction industries grapple to consume good quality RS. Various research studies have been started on finding the most suitable, cost effective and readily available alternatives to solve this problem [3]. On the other hand, the survey study carried out by Branavan & Konthesingha [6] among the local construction industries in Sri Lanka, reveals that 19% of large-scale and 5% of small-scale construction companies have already started using manufactured sand (M Sand) and OS in their construction activities. This statistical analysis can also be directly applied to countries around the world with minor deviations, which are utilizing M Sand and OS as the main alternatives. However, it can be noticed that since the contractors are incognizant to use different alternative types with optimum performance to achieve good quality mixes. Therefore, this study contemplates the physical properties and quality of M Sand, OS and blended sand meeting the requirements of ASTM C33 [7], M Sand and OS can be considered as the principal alternatives to RS that can significantly control the fresh and hardened properties of concrete and mortar mixes as well as the overall cost for construction [5,8-11]. Intensely, analysis of the properties of blended sand with the above alternatives by using a combined fine aggregate technique, makes this study more attention. Conclusion of this study was derived from performing physical and quality characterizing tests for all main types of sand individually and blending selected M Sand types with OS.

RS is naturally available, portraying both positive and negative attributes as a fine aggregate. Sand is processed by attrition and water actions, make the particles with better rounded shapes and smooth surface texture [12,13]. Clean river sand with rounded shaped particles makes the mixes with good workability without the addition of excess water, cement or admixtures [13,14]. However, clay and silt content in RS making concrete and cement mortar mixes less durable and strength [12,15]. In all cases grading of RS performs well, thus lower fineness modulus makes the mixes more stable by limiting the void content. M Sand is a purpose made crushed fine aggregate from hard-granite rocks involving crushing, screening and washing processes and designed for use in concrete and cement mortar mixes to substitute natural river sand [16-18]. Since the source for M Sand production is parent rock which is a composite material bound with minerals and elements, giving both positive and negative impacts to cement based mixes. Cement Concrete & Aggregates Australia [16] recommended some suitable rocks as the sources for M Sand production. M Sand is processed through several crushing stages at quarries which affect the physical properties especially, particle shape, surface texture and gradation [19]. In normal conditions, M Sand is linearly distributed and carries higher fines (stone dust <0.075mm of 10-20%) which drastically increase the water requirement in the mixes, durability, packing density [13,20] and reduce the bleeding. Beixing, et al. [5] in his studies, states that increased micro-fines in M Sand enhances the harsh-mixes with high abrasion resistance and poor finish ability and decreased strength. Rock samples are crushed to M Sand having less circularity/angular shaped particles which raises the particle inter-locking and ultimately develops inflated strength mixes [18-21]. Adverse effects to the workability of mixes can also arise due to the rougher surface texture of M Sand particles [11,19,20]. But on the other it hand increases compressive and flexural strengths [5] and the bond between the particles [13]. An effective alternative following M Sand is OS, which is dredged from offshore beds having most similarities with natural river sand particles. Dredging OS is not a feasible solution due to environmental concerns [22]. Luckily, Aswath [4] states that extracting sand from 15m below sea level effects less environmental and biological impacts. The circularity of OS particles is similar to river sand [21] and dredged marine sand has a homogeneous grain size distribution [23,24] enhances workability of mixes. Klemm [23] describes the causes for rounded shaped and polished particles in OS due to the action of waves and wind that move the particles rub each other and by dissolving soluble substances. However, from the research studies carried out by Shahri & Chan [25] and statements by Harrington & Smith [26], it can be concluded that the above properties and composition depend on the location of dredging. Swelled chloride and salt content contribute demerits to both concrete and cement mortar mixes by affecting time of set, increasing drying shrinkage and causing efflorescence [1,27,28]. Seashells in OS demand the requirement of cement paste to overcome workability issues and decline compressive strength by enlarging void content [1]. Designing blended sand as fine aggregate is expected to be the most optimum solution to replace natural RS in both concrete and cement mortar mixes. This method is highly encouraged because characteristics of M Sand particles (angular shape and rough surface texture) can be resembled partially by blending OS particles (rounded and smooth surface), which can ameliorate the quality of cement-based mixes and outcome gap-graded fine aggregate. Once the blend is established, the properties of individual components (i.e. properties of M Sand and OS alone) critically influence the total blended sand properties and mix performance [16]. Proper blending of sand types results in maximum packing density (i.e. reduced void content). It can also lessen the volume of cementitious paste required thus reaches lower shrinkage, increased durability, diminished rate of hydration and lower cost of the mixes [1,10,20,29]. Absorption problems can also be lowered by combining both aggregates than when they are acting alone, which directly correlates the bond between the aggregate particles and cement paste [13].

2. RESEARCH SIGNIFICANCE

Literatures show a broad investigation has already been followed up on the physical properties of natural RS and M Sand linked to mechanical and plastic properties of concrete. Particularly, inspections on the shape, surface texture and gradation characteristics of M Sand and RS using various techniques have been assessed to an extent. Also, some studies have been executed by combining the above properties of M Sand with the effects of the manufacturing process. As the optimized concept of aggregates in cement-based mixes, researchers are now investigating by mingling fine aggregate with coarse aggregate for better performance. However, fresh and hardened state properties of both concrete and cement mortar can be modified when combined fine aggregate is used in the mixes. For example, blending M Sand and OS can improve various properties of mixes as they are having contrast physical properties. Therefore, finding an optimum blended solution as the alternative fine aggregate for natural RS in concrete and cement mortar to overcome the environmental and technical problems has become as the current theme. To achieve the above theme, an extensive objective of this work was set to investigate the eligibility of blended sand with M Sand and OS to fully replace natural RS by examining physical parameters and quality through several analyses to improve the overall concrete and cement mortar mix performance.

3. MATERIALS AND EXPERIMENTS

3.1 Materials

Four different types of fine aggregate samples were utilized for the experiment works; RS, OS and manufactured sand from two different rock types: MS(HG) and MS(CH). RS was collected from a river bed while OS was collected from open stockpiles after a considerable period of washing and sieving. M Sand produced from Charnockite and Hornblende-Gneiss rocks were selected and obtained directly from the quarries for this study. Fig. 1 shows the images of selected sand types and Table 1 includes the schedule of blended sand types used for this study. X-Ray Fluorescence (XRF) analysis was done as the quantitative method for investigating the chemical compositions of each sand type considered. 'Spectro-XEPOS XRF Spectrometer' was used for the above analysis and Table 2 lists down the chemical compositions of each sand type.

3.2 Methods

Considerable sets of laboratory experiments were conducted to conclude the appropriateness of selected alternative sand types to be used in concrete and cement mortar mixes. Here, sand types were used alone and blended forms as the inputs for experiments. In this paper, the laboratory tests conducted are divided into five subsections: appearance, gradation, densities, absorption and surface moisture and hazardous materials. As the initial process, particle size, shape, surface texture and total specific surface were analyzed through quantitative techniques. The appearance of sand types influences freshly mixed concrete and cement mortar than hardened state properties. ASTM standard tests and some of the approved tests previously conducted by the authors were followed up

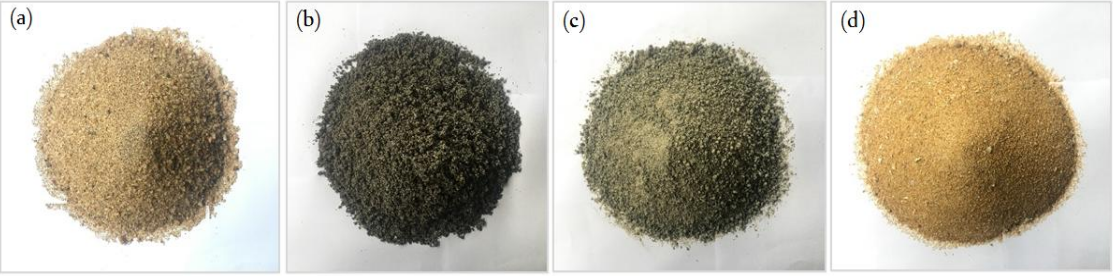

Fig. 1. Fine aggregate types: RS (a); MS(HG) (b); MS(CH) (c); OS (d)

Table 1. Schedule of blended sand types

Sand code	Proportions %			
	MS(HG)	MS(CH)	OS	RS
BHO1	25	-	75	-
BHO2	50	-	50	-
BHO3	75	-	25	-
BCO1	-	25	75	-
BCO2	-	50	50	-
BCO3	-	75	25	-

BHO: Blended sand with MS(HG) and OS
BCO: Blended sand with MS(CH) and OS

Table 2. Chemical composition of sand types (%)

Sand type	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	SO_3	Na_2O	K_2O
RS	97.53	2.84	0.19	0.00	0.00	0.00	0.00	0.76
MS(HG)	73.59	7.59	4.83	3.07	1.02	0.00	1.75	1.33
MS(CH)	72.01	7.83	2.09	3.95	0.25	0.00	2.08	2.54
OS	65.84	15.24	4.78	2.55	2.09	0.00	0.00	0.00

for quantitative analysis. Indirect measurements of particle shape and surface texture were determined using ASTM C1252 [30] and ASTM D3398 [31]. Gradation is the dominant parameter of sand which affect cement and water requirements, consistency, workability, porosity, shrinkage and durability of both concrete and cement mortar. Here, for sand particles above 0.075 mm, a sieve analysis test was performed according to ASTM C136 [32] and ASTM D7928 [33] was followed to determine the gradation of particles below 0.075 mm using hydrometer test. Sand samples were oven-dried for 24 h and cooled down to achieve a constant mass before the above tests. Some additional information on the variation of fineness modulus (coarseness of sand) was directly obtained from the sieve analysis test and optimization of better sand type for concrete and cement mortar mixes using 0.45 power chart method. Different types of densities were considered here by determining specific gravity, loose (uncompacted) density and packing (compacted) density which ultimately influences the density of concrete and cement mortar mixes at different compaction rates. Specific gravity and loose density were tested using density bottle method and the test illustrated in ASTM C1252 [30] respectively. To find packing density values, a rodding experiment was followed up using ASTM C29 [34] standard using the selected sample sizes mentioned in the standard. ASTM C1252 [30] was also referred to determine the void content of different sand types used in this study. Additionally, by using the test method mentioned in ASTM C1252 [30], the performance of flowability under gravity with respect to time considering various parameters for each main sands and blended types were also examined and used as a supportive study. Total moisture content, surface moisture and water absorption were analyzed through standard test methods stated in ASTM C70 [35], which are the main parameters used to control total water demand and for correct batching process for concrete and cement mortar mixes. Due to the variations in physical characteristics of sands selected, bulking of sand is also considered as an important influencing parameter, analyzed in this study. Moreover, deleterious substances present in sand are the causes for strength reductions, popouts, variations in setting times, water demand, significant volume changes, rate of hydration, etc. Therefore, this study also examined clay and friable particles and fines (less than 0.075 mm) using ASTM C142 [36] and ASTM C117 [37] respectively. Silt content test was performed by a settling method using a diluted NaCl solution.

4. RESULTS AND DISCUSSION

4.1 Appearance

Physical properties such as color, shape, size, and texture are the preliminary aspects of sand which can be applied to compare the behavior between more sand types. This concept is defined as ‘Soil Taxonomy’, a classification of groups of sand. This section involves an analysis of all the above basic characteristics for each sand type considered in this study. First classification can be done using the color of sand particles which is influenced by the weathering action/crushing process of rocks. Rocks with different minerals and elements are shuttered through various energy impacts which gives the variations to color. Moreover, specially the color of natural aggregates such as RS and OS are also affected by environmental concerns like aerobic and anaerobic conditions and depth of extraction. However, the color of crushed sand/M Sand is mainly due to the constituents of parent rocks utilized for the manufacturing process. But also, there can be some small color deviations due to the washing process. To have a clear explanation, a standard method called ‘Munsell Color System’ is used in this study for each sand types mentioned under Section 3.1. This standard system has three main components: hue (a specific color), value (lightness to darkness) and chroma (color intensity) [38]. Representative sand sample was held next to the color code to find Munsell color notation for the visual inspection. Visually matched color notations are: RS – 10YR 8/4 (pale brown), MS(HG) – 7.5YR 5/0 (strong gray), MS(CH) – 10YR 6/2 (light gray) and OS – 10YR 7/6 (very strong yellow). It can be noticed that naturally available aggregates such as RS and OS are having lighter color than M Sand due to the years of washing which can substantially reduce the mineral compounds and change the sand compositions. M Sand type used here are crushed instantaneously from metamorphic rocks which consist of mostly darker minerals. However, screening of fine aggregates to determine performance and quality cannot only rely using this color analysis. Fresh and hardened state properties of concrete and cement mortar are highly influenced by the shape of both fine and coarse aggregates. Here, fine aggregates considered are both naturally available and manufactured where shape characteristics of each type can be varied. A sand particle can have a shape rounded, angular/cubical, irregular or flaky. RS and OS are weathered rock specimens, and have been subjected to years of washing which sculpted the particles with rounded shapes through attrition. However, M Sand is produced instantly which enables well-defined edges at the planar face intersections called angular particles. Other shapes such as irregular particles are also formed by attrition and flaky particles have thickness relatively smaller to the width or length. This section covers the angularity comparisons of four major sand types and blended types used in this study by the most common quantitative technique suggested by Shergold (1953) cited in [39]. This method includes the identification of angularity number (f_H) with respect to mass of sand sample after compaction (M_s), the weight of water to fill the container (M_w) and specific gravity of sand type (G_s) from Equation 1, for each sand type by contemplating the percentage of voids after a sufficient number of blows. Murdock (1960) cited in [40] modified the above method with an index number system by implementing Equation 2 for angularity index (f_A) by using the angularity number obtained in the previous method. Table 3 lists down the obtained values of f_H and f_A for each sand code.

$$f_H = 67 - \frac{M_S \times 100}{M_W \times G_S} \tag{1}$$

$$f_A = \frac{3 \times f_H}{20} + 1.0 \tag{2}$$

Fine aggregate with angularity number from zero to 11, can be considered as the suitable aggregates for concrete and cement mortar [39]. Rounded shape aggregates take lower angularity numbers/angularity indexes while angular/cubical shape aggregates have higher values. From Equation 1, it can be said that if the angularity number is zero, the solid volume of aggregate is 67 % and if the angularity number is 11, the solid volume of aggregate is 56 % which shows the impact of the shape of particles. Table 3 values highlight that RS and OS particles are having lower angular indexes while higher indexes can be noticed with manufactured sand. When blending M Sand with OS, with the increased replacement levels, the reduction in angularity indexes can be observed due to the replacement of M Sand with rounded OS particles. This reveals that the degree of angularity is increased with M Sand types due to the crushing stages and characteristics of rocks. Rounded shape aggregates such as RS and OS can produce concrete and mortar mixes with higher workability due to the slip ability of sand particles. On the other hand, high strength and durable concrete and cement mortar can be obtained using angular/cubical M Sand aggregates which enhance internal frictional resistance due to the particle interlocking and thus increases the bond strength between aggregates and cement paste [16,41]. Therefore, blended sand can be the most appropriate fine aggregate type in terms of fresh properties, hardened properties and economy of the mixes. Not only the shape but also surface texture influences the properties of concrete and cement mortar. The surface texture of an aggregate particle can be varied from smooth to rough. A standard testing method recommended by ASTM D3398 [31] is used here to determine an index method with respect to both shape and surface texture of fine aggregate particles. Particle index values (f_I) obtained here are also based on the void content in two different conditions: V_{10}: void content after 10 drops per layer and V_{50}: void content after 50 drops per layer, particle index of each size fraction (I_a) and aggregate passing percentage (P) (refer Equation 3 and Equation 4).

$$I_a = 1.25 \times V_{10} - 0.25 \times V_{50} - 32.0 \tag{3}$$

$$f_I = P \times I_a + 100 \tag{4}$$

Table 3. Angularity numbers & indexes of sand types

Sand code	Specific gravity (G_s)	Angularity number (f_H)	Angularity index (f_A)
RS	2.64	5.019	1.753
MS(HG)	2.71	6.045	1.907
MS(CH)	2.70	6.042	1.906
OS	2.67	4.926	1.739
BHO1	2.68	5.074	1.761
BHO2	2.69	5.244	1.787
BHO3	2.70	5.333	1.800
BCO1	2.68	5.142	1.771
BCO2	2.69	5.240	1.786
BCO3	2.69	5.160	1.774

Table 4 shows the particle index values (f_I) calculated for each size fraction and sand types considered in this study. Higher index values are with rougher surface texture M Sand particles and RS and OS particles are derived with lower index values which can be considered as smooth texture sand types. The bonding capacity with hydraulic cement paste in concrete and cement mortar mixes is also influenced by the surface characteristics, where rough texture M Sand particles can produce better bonds than river sand and offshore sand particles. However, the degree of roughness of individual size fractions also determine the overall performance of the fine aggregate type. From the calculated values listed in Table 4, it can be clearly understood that particle size fractions from 1.18 mm to 0.3 mm of RS and OS are the dominant sizes, increase the degree of roughness of each sand type. But when considering MS(HG) and MS(CH), particles fall within the size fraction of 5.6 mm to 0.3 mm are having greater roughness. Therefore, it can be concluded that due to the higher inclusion of rough particles, M(HG) and MS(CH) are seemed to be rougher than RS and OS. Moreover, the combined effect of shape and surface characteristics finally determines the total specific surface of a fine aggregate type. Finer particles act the major role for the surface area of a sand type than coarser particles. Larger specific surface, consumes more water or increase the water demand in concrete and cement mortar mixes to enable the lubricating effect to achieve required workability. This lubricating effect can be achieved by the finer particles when acting between coarser particles to reduce the frictional resistance. Murdock (1960) cited in [40] suggested a method for determining weighted surface index (f_X) for a sand type which is used here to analyze specific surfaces. Weighted surface index (f_X) values which are shown in Table 5 can be calculated using Equation 5 considering each size fractions with the percentage of particles within sieve range.

(P_s) , individual surface index for the fraction (if_X) and a constant $(C = 330)$. OS and RS have arrived with higher surface index values that define the larger specific surfaces than MS(HG) and MS(CH). This is due to the higher content of particles of river sand and offshore sand fall within the range of 1.18 mm to 0.3 mm while most of the M Sand particles lie within the range 5.6 mm to 2.36 mm and 0.65 mm to 0.3 mm. However, it should be noted that MS(HG) and MS(CH) have a considerable number of fines (less than 0.075 mm) than natural aggregates which can also affect the water demand in the mixes that failed to be addressed. A pictorial representation (refer Fig. 3) can be referred for all the above characterization among each size fractions of the sand types used in this study.

$$f_X = \frac{\sum(P_S \times if_X)+C}{1000} \qquad (5)$$

Relationship between surface index (f_X) , angularity index (f_A) and particle index (f_I) can be made with the selected major sand types and blended types. Fig. 2 represents the individual relationships between the shape characteristics and specific surface and texture characteristics and specific surface. Both relationships show linear behavior and inverse proportionality. This is obvious that more angular and rough texture particles can reduce the total specific surface due to the spaces fetched by angular and sharp edges. As mentioned early, both shape and texture influence the specific surface of a sand type. Therefore, a combined relationship with the above parameters can be made with the multiple regression model. Here, angularity index (f_A) and particle index (f_I) which are the characteristics of shape and texture of sand particles can be considered as independent variables and surface index (f_X) as the dependent variable. A linear model can be developed to determine the total specific surface of a fine aggregate type with respect to the angularity and texture of particles (with adjusted R^2 value of 0.7992) as shown in Equation 6.

$$f_X = 2.575 - (0.576 \times f_A) - (0.274 \times f_I) \qquad (6)$$

4.2 Gradation

Particle size distribution of particles greater than 0.075 mm of sand types RS, MS(HG), MS(CH), and OS are shown in Fig. 4 from the sieve analysis test. Lower and upper limiting zones confirming zone II stated in ASTM C136 [32] are also used in this graph to determine the suitability of sand types along in the mixes. Proper variation in RS can be observed where the gradation curve lies within the required limiting zone. However, OS and MS(HG) particles in the range of 2.36 – 0.65 mm lie out of lower and upper limitations where this shows the scarcity and abundance of particles in the above range. But MS(CH) gradation curve marginally touches the indicated limit zones. This problem can be overcome by shifting the curves into the required limiting zone by blending OS and M Sand at different percentages. Fig. 5 shows the

Table 4. Particle index (surface texture properties) of sand types

Sand code		Particle size fraction (mm)					
		5.6 – 2.36	**2.36 – 1.18**	**1.18 – 0.65**	**0.65 – 0.30**	**0.30 – 0.15**	**0.15 – 0.075**
RS	1	2.60	2.61	2.61	2.62	2.61	2.62
	2	38.908	42.515	42.977	41.243	40.384	40.276
	3	37.081	41.332	41.975	40.013	39.300	39.449
	4	7.365	10.811	11.227	9.550	8.655	8.483
	5	255.0	548.1	610.6	683.7	97.5	29.1
	6	11.149	23.963	26.695	29.891	4.263	1.272
	7	0.821	2.591	2.997	2.855	0.369	0.108
MS(HG)	1	2.69	2.71	2.71	2.73	2.71	2.72
	2	42.354	45.227	46.202	47.733	51.487	51.862
	3	39.588	44.265	44.581	42.200	45.235	46.100
	4	11.045	13.468	14.607	17.117	21.050	21.303
	5	892.5	420.2	283.3	412.4	215.5	260.4
	6	32.682	15.387	10.374	15.101	7.891	9.535
	7	3.610	2.072	1.515	2.585	1.661	2.031
MS(CH)	1	2.67	2.69	2.71	2.69	2.70	2.70
	2	41.061	44.082	45.429	44.271	45.525	44.607
	3	38.412	41.805	44.377	42.915	44.231	42.853
	4	9.724	12.651	13.692	12.610	13.848	13.045
	5	554.4	582.7	319.9	368.3	161.5	202.0
	6	24.350	25.593	14.050	16.176	7.093	8.872
	7	2.368	3.238	1.924	2.040	0.982	1.157
OS	1	2.61	2.60	2.63	2.66	2.68	2.67
	2	46.215	45.511	42.723	41.302	42.261	42.258
	3	45.055	43.650	40.861	40.073	41.490	41.465
	4	14.505	13.976	11.189	9.610	10.454	10.456
	5	24.5	136.4	549.7	1191.0	340.9	120.9
	6	1.034	5.756	23.197	50.260	14.386	5.102
	7	0.150	0.804	2.595	4.830	1.504	0.533

1 - Specific gravity, G_s
2 – Voids in aggregate compacted at 10 drops per layer, V_{10} *%*
3 – Voids in aggregate compacted at 50 drops per layer, $V_{5\ 0}$*%*
4 – Particle index, I_a $(= 1.25V_{10} - 0.25V_{5\ 0} - 32.0)$
5 – Weight of aggregate retained in the sieve, W *(g) (from sieve analysis test)*
6 – Aggregate grading, $P\,\%\ (= [W/\ Total\,mass\ of\ sand\ sample] \times 100)$
7 – Weighted particle index, $f_I\ (= P \times I_a + 100)$

shifting of curves for blended sand types of offshore sand with MS(HG) and MS(CH) respectively. Blending 50% MS(HG) with 50% OS can effectively shift the gradation curve than considering other blending ratios. But each selected blending percentages of MS(CH) with OS performed well in achieving proper gradation. The curves shown above concludes that a 50% blending level in both cases shows a better size distribution where a smooth grading curve can be observed. The above analysis can be clearly identified from numerical values using the coefficient of uniformity (C_u) and coefficient of curvature (C_c) which are the geometric properties of a gradation curve and the values are shown in Table 6. Fineness modulus (FM) is used as an index here to compare the coarseness of alternative sand types and blended sand types. From the experiment results FM values were observed as 3.113 for RS, 3.086 for MS(HG), 3.107 for MS(CH) and 2.128 for OS which highlights the increased coarseness of M Sand and more fineness of OS than RS. Fig. 6 shows the variation of FM values (2.37 to 2.86) for MS(HG) + OS & 2.37 to 2.85 for MS(CH) + OS) with blending percentages where similar variation is observed with both types of M Sand with OS and increased coarseness than RS for all replacement levels. Various sand types when they are acting alone and blending with others, the overall density of sand can be varied which also finally affects the density of concrete and cement mortar mix. In this study, a method for graphical representation method '0.45 power chart' is used in which the aggregate cumulative passing percentages are plotted against the sieve sizes raised to the power of 0.45. A straight ‘power line’ in this graph from the origin to the maximum aggregate size defines the optimum grading for density in the mix and the curve approaching the power line is said to be the denser sand which can minimize voids and therefore cement and water demand of the mix. Natural sand types; RS and OS stay far away from the power line while both M Sand types are approaching due to the increased fines content. From Fig. 7, reciprocal behavior can be noticed with both M Sand types when blending with OS. With increased replacement levels the density of blended sand was reduced. For example, the rate of approach to power lines was decreasing when replacing both MS(HG) and MS(CH) with 25% to 75% with OS. This is from which the considerable number of fines responsible for higher density was replaced by larger OS particles and this brings some voids to the sand mixture.

However, blended sand with all replacements shows positive results with density than RS. So, required denser fine aggregate can be produced with blended sand than RS which can also be used as a tool to reduce the cost with respect to the density of finished concrete and cement mortar and workability. The governing parameter for the above density variation is the particles passing 0.075 mm (No.200) sieve in sand called “fines”. A sand type can contain various types of fines (clay and friable particles, silt, organic impurities and soft and lightweight particles) with different amounts based on their particle size. So, it is mandatory to determine gradation, available types and the amount present of fines in a sand mix before utilizing as they can cause

Table 5. Surface index (total specific surface) of sand types

Sand code		Particle size fraction (mm)						f_X
		5.6 – 2.36	**2.36 – 1.18**	**1.18 – 0.65**	**0.65 – 0.30**	**0.30 – 0.15**	**0.15 – 0.075**	
RS	1	11.149	23.963	26.695	29.891	4.263	1.272	1.084
	2	4	7	9	9	7	2	
	3	44.596	167.741	240.255	269.019	29.841	2.544	
MS(HG)	1	32.682	15.387	10.374	15.101	7.891	9.535	0.872
	2	4	7	9	9	7	2	
	3	130.728	107.709	93.366	135.909	55.237	19.070	
MS(CH)	1	24.350	25.593	14.050	16.176	7.093	8.872	0.946
	2	4	7	9	9	7	2	
	3	97.400	179.151	126.450	145.584	49.651	17.744	
OS	1	1.034	5.756	23.197	50.260	14.386	5.102	1.146
	2	4	7	9	9	7	2	
	3	4.136	40.292	208.773	452.340	100.702	10.204	
BHO1	1	8.946	8.164	19.991	41.470	12.762	6.210	1.078
	2	4	7	9	9	7	2	
	3	35.784	57.148	179.919	373.230	89.334	12.420	
BHO2	1	16.858	10.571	16.785	32.680	11.138	7.319	1.009
	2	4	7	9	9	7	2	
	3	67.432	73.997	151.065	294.120	77.966	14.638	
BHO3	1	24.770	12.979	13.579	23.891	9.515	8.430	0.941
	2	4	7	9	9	7	2	
	3	99.080	90.853	122.211	215.019	66.605	16.860	
BCO1	1	6.863	10.715	20.910	41.739	12.563	6.044	1.096
	2	4	7	9	9	7	2	
	3	27.452	75.005	188.190	375.651	87.941	12.088	
BCO2	1	12.692	15.674	18.624	33.218	10.740	6.987	1.046
	2	4	7	9	9	7	2	
	3	50.768	109.718	167.616	298.962	75.180	13.974	
BCO3	1	18.521	20.634	16.337	24.697	8.916	7.930	0.996
	2	4	7	9	9	7	2	
	3	74.084	144.438	147.033	222.273	62.412	15.860	

1 - P_s: % Particle within size fraction from sieve analysis test

2 - if_x : Individual Surface Index for size fraction

3 - $P_s \times if_x$

both benefits and detriments to concrete and cement mortar properties. Determination of fines types and amount present in the selected sand types are described under Section 4.5 and here this part covers the particle size distribution of fines of the selected sand types for this study. Fig. 8 shows the generated gradation curves plotted with respect to percentage finer (%) of the considered size fraction ranging from 0.0683 mm to 0.0014 mm. MS(HG) fines show a higher percentage finer for each size fraction considered while gradation curves of offshore sand and river sand fines convey the same behavior. MS(CH) fines manifest the least percentage passing for each size fraction than other sand types. It is obvious that M Sand is produced through several crushing stages that enable higher fine content than natural river sand. However, based on Fig. 8 it can be noticed that MS(CH) has lower passing percentages than RS and OS. So, there is a possibility of having higher passing percentages of particles less than 0.0014 mm of MS(CH) which is not considered in this test.

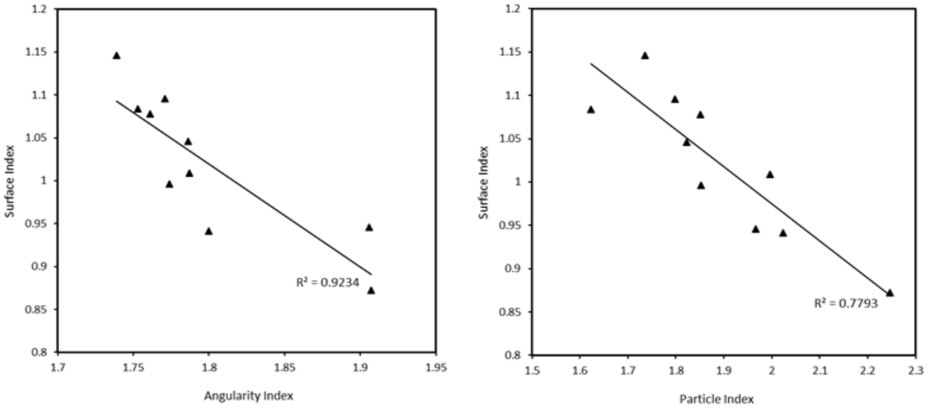

Fig. 2. Relationships between angularity index, particle index and surface index

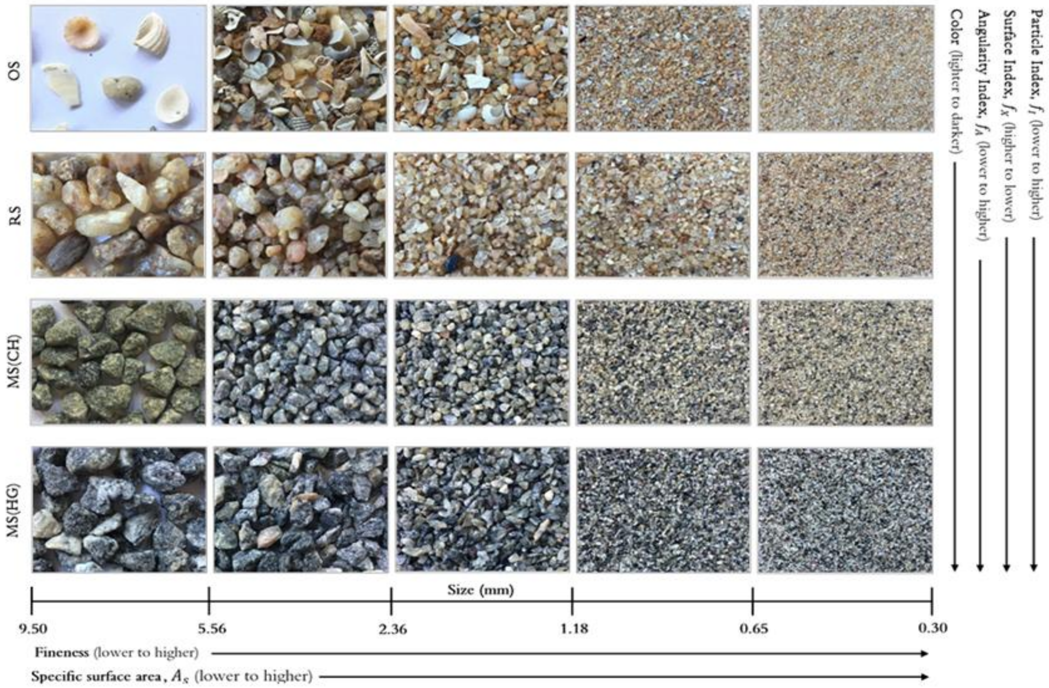

Fig. 3. Variations in physical properties

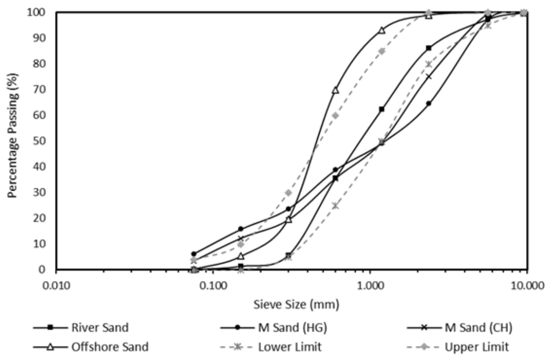

Fig. 4. Gradation curves of particles greater than 0.075 mm

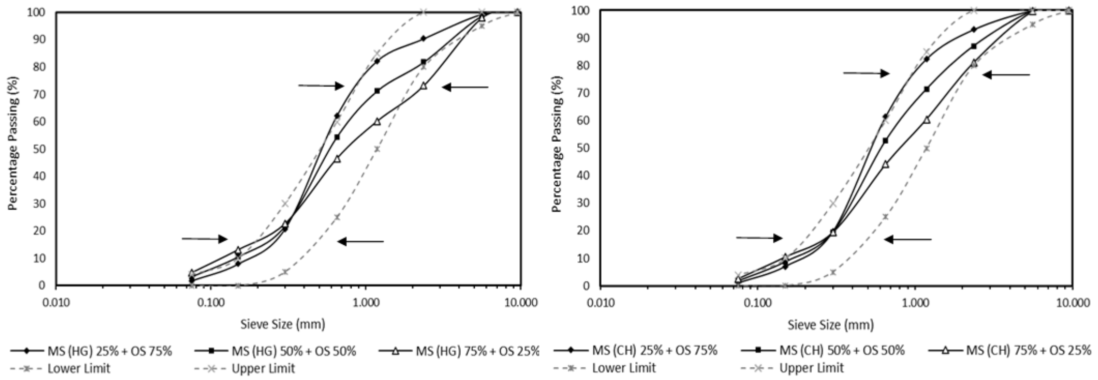

Fig. 5. Shifting the curves with blended sand: MS(HG)+OS & MS(CH)+OS

Table 6. Coefficient of uniformity and curvature values

Sand code	Cu	Cc	Required range
RS	3.571	0.642	for well graded sand:
MS(HG)	20.000	0.841	$C_u > 4 – 6$
MS(CH)	12.30	1.108	$1 < C_c < 3$
OS	2.429	1.210	for poorly/uniformly graded sand:
BHO1	3.222	1.383	$C_u < 4$
BHO2	4.667	1.304	
BHO3	10.000	1.056	
BCO1	3.105	1.156	
BCO2	4.471	1.177	
BCO3	8.000	0.980	

4.3 Degree of Compactness

Specific gravity, loose density, packing density and void content was considered as the main frameworks and determined through corresponding standard test methods described under Section 3.2. Furthermore, sand actions against gravity were also checked for each sand type alone and blended sand categories mentioned in Table 1. This section provides the relevant test results from the above experiments.

The relative density/specific gravity values can be used here for the basic comparison of unit weight of sand types considered in this study. Because the specific gravity of sand determines self-weight of concrete and cement mortar in the hardened state as sand is the major constituent covers 60 – 70% of the total volume of concrete and plays 100% aggregate role in cement mortar. So, these specific gravity values can be used for mixture proportioning and partially as an approximate durability factor for hardened state mixes. In this study the relevant specific gravity values are in the range between 2.64 to 2.71 were determined as oven dry basis where sand particles do not contain any absorbed or free water. The void content of sand is also a key factor that influences water demand and cement paste requirements in mix design and thus the cost of the mix [1,42,43]. Voids present in sand are affected by shape & surface texture of particles and gradation. Here, it can be observed that M Sand types reveal more void content (2.09 % to 2.68 %) than RS and OS show a small deviation from river sand. Angular shape and rougher surface texture M Sand particles raise the amount of void than round shape and smooth surface texture RS and OS particles. All the sand

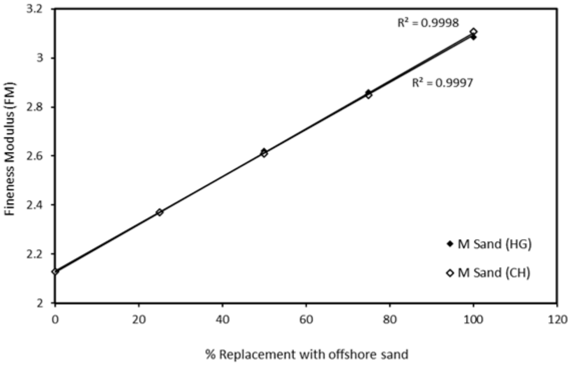

Fig. 6. Variation of fineness modulus with blending ratios

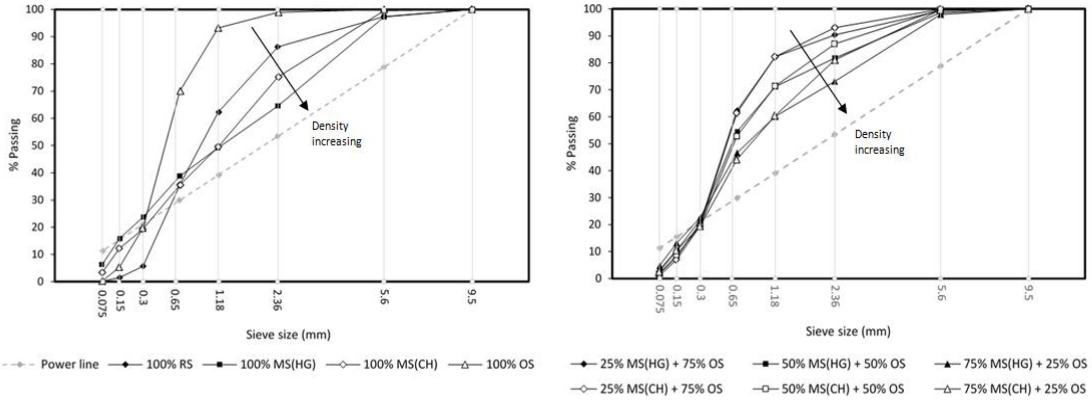

Fig. 7. 0.45 Power chart (main sand types & blended sand types)

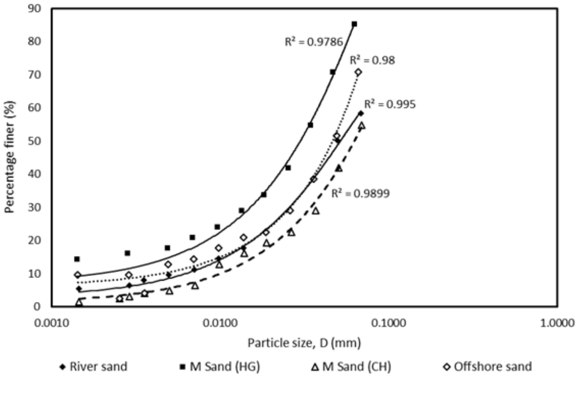

Fig. 8. Gradation curves of particles less than 0.075 mm

types considered here are within the common range of 30 – 45 % which are suitable as fine aggregate. Table 7 lists all the results of specific gravity and void content values of the above sand types and Fig. 9 shows the variations of loose and packing densities with fixed error bars of different sand types. Here, loose densities were determined without any compaction or external forces while packing densities were obtained through rodding procedure using a considerable an amount of compacting forces mentioned under Section 3.2. Increased deviation in both loose and packing densities can be noticed between MS(HG) and MS(CH) compared with RS and OS. This can be mainly due to the higher unit-weight of sources (parent rocks: Hornblende-Gneiss and Charnockite) for M Sand production. Loose density of each sand type lies within the required zone (1200 – 1750 kg/m^3) to perform as a fine aggregate. Both highest loose and packing density values (1783.943 kg/m^3 & 1915.161 kg/m^3) were noticed with MS(HG) and MS(CH) standing next to it. Reductions from 11.184% to 1.31% and from 5.42% to 2.04% of loose and packing density values respectively were achieved with 75% to 25% replacement levels with OS. Same trend can also be noticed when replacing MS(CH) with OS and the difference between loose and packing density values of all blended sand types seem to be getting higher by lowering replacements with OS due to the inclusions of micro-fine. So, for a better durable and lower weight concrete and cement mortar, blended sand having MS(HG) and MS(CH) with replacement levels of 75% to 50 % with OS can be used as an alternative to RS.

Flow cone according to ASTM C1252 [30] was also used here as an alternative tool to determine the flowability of different sand types under gravity with respect to time. In this method, the mass of the oven-dried sample was kept constant for each test and allowed to pass through the cone into a predefined cylinder under gravity. Stopwatch was started after opening the hole of cone and stopped once sand emptied the cone. Here, the time taken can be affected by the physical characteristics of different sand types as well as loose density and this is well illustrated in Fig. 10. Graphs show the variations of time taken against blending ratio, loose density, angularity index, particle index and surface index. RS and OS consumed 18 s and 15 s to empty the cone respectively while MS(HG) and MS(CH) took higher times (28 s and 26 s) when acting alone. First graph describes the variation based on the blending percentages with OS. At lower replacement levels with OS, the time taken to empty the cone is seemed to be lower for both MS(HG) and MS(CH) due to the higher presence of angular and rough texture particles. A gradual increase in flow time can be observed by improving the blending ratios. Flow times against loose density of sand are shown in the second graph and here also a gentle slope can be identified with both blended sand types with similar behavior. However, a considerable deviation of flow times can be noticed between loose densities 1700 – 1750 kg/m^3. The trends with particle physical characteristics such as shape and surface texture appear in third and fourth graphs respectively. Increased time consumption for both M Sand types is due to the higher frictional resistance between angular shape and rough texture particles than round and smooth texture natural sand particles. This internal friction reduces the flowability of blended sand at lower replacements with OS. The combined behavior of shape and texture characteristics influences the total specific surface and the variation with flow time is plotted in the fifth graph. Indirect proportional trends can be noticed here where the inclusion of OS particles in blended sand types can lessen the void content by filling the voids between larger M Sand particles. This increases the total specific surface of sand and thus reduces the time to empty the cone. Above relationships can be used as a reference for workability of concrete and cement mortar mixes. During the compaction process of fresh state mixes, aggregates should have enough flowability to achieve the required workability and to reduce the honeycombs that arise with molding. Therefore, by using the above graphs as an alternative to RS, a combined sand with 25% - 50% of M Sand and 75% - 50% OS can be applied in the mixes.

Table 7. Specific gravity and void content

Sand code	Specific gravity	Void content %
RS	2.64	38.143
MS(HG)	2.71	38.942
MS(CH)	2.70	39.167
OS	2.67	38.256

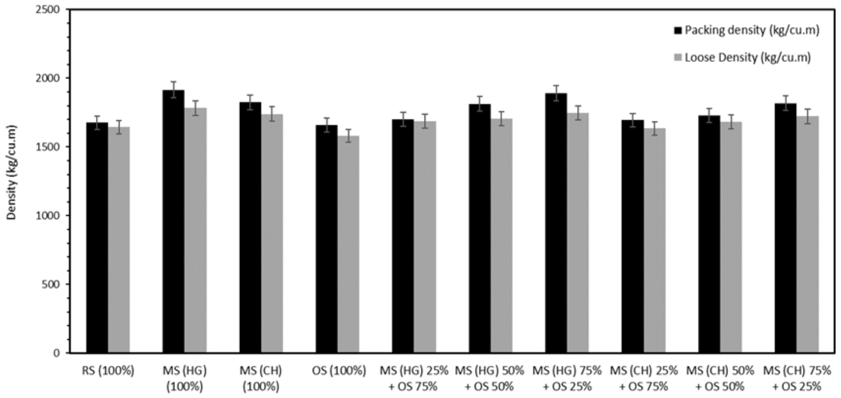

Fig. 9. Loose and packing densities

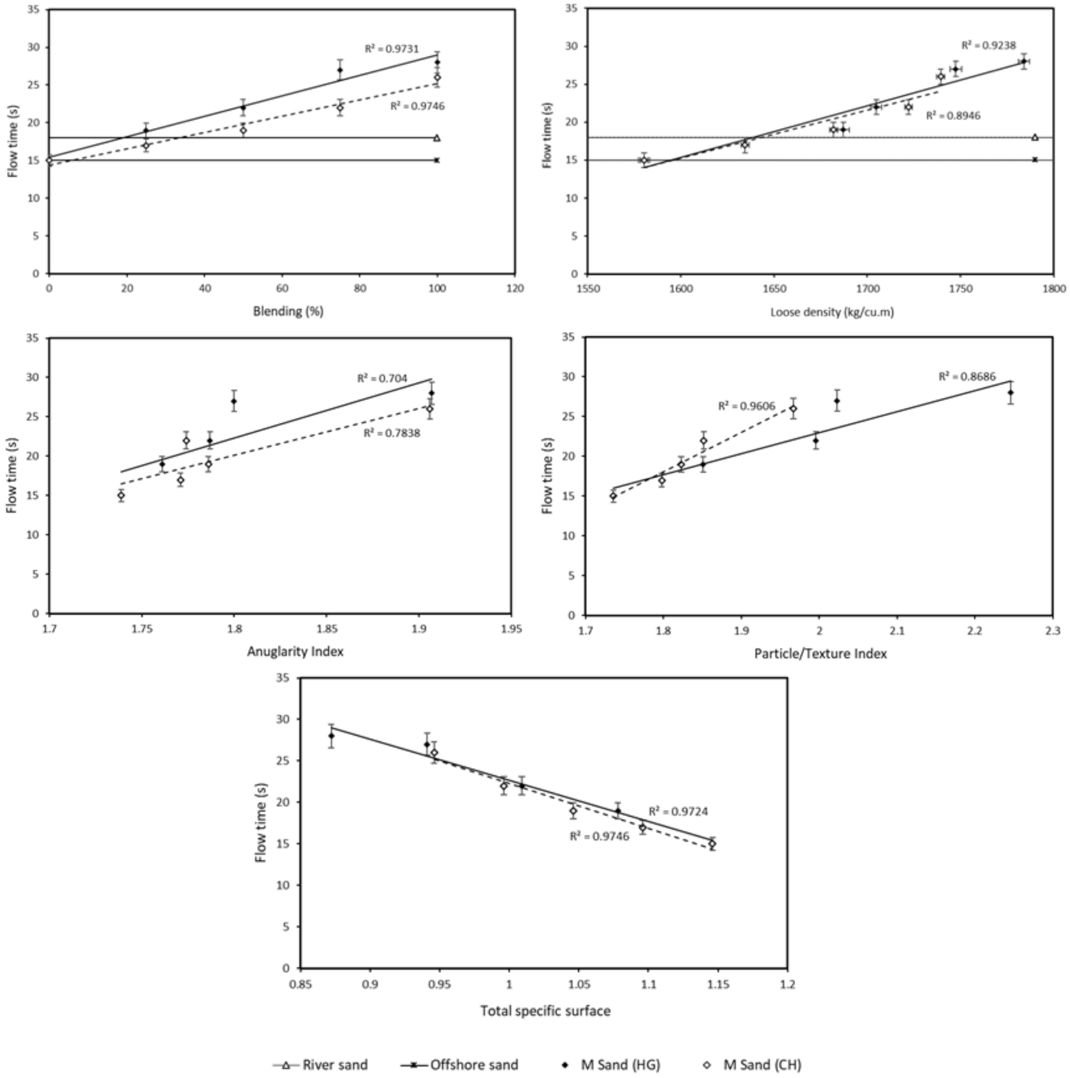

Fig. 10. Relationships between flow time and various parameters

4.4 Absorption and Surface Moisture

The absorbing capacity and performance to resist water on the surface can be varied for different types of sand. This is not a parameter to define the quality of fine aggregate but should be identified to overcome the problems that arise with total water content and demand for concrete and cement mortar mixes. Absorbed water and surface moisture are primarily not only dependent on the surface characteristics of sand particles, but also the environmental conditions. Here, this behavior is studied and compared for each individual sand with other sand types used for this study. Different sand types consist of varying total surface area and pores present internally and, on the surface, which are the dominant parameters considered here. Fig. 11 reveals the calculated absorption and surface moisture content of each primary sand type. The total moisture content (M_t) of a sand type can be expressed as the summation of the amount of water absorbed (M_{ab}) by the pores in each sand size fractions and moisture present on the surface (M_s) of particles due to the degree of texture and angularity. A variation can be plotted with the absorption of water by the sand types against surface index (f_x) according to Fig. 12 and a linear relationship Equation 7.

$$M_{ab} = 2.438 - (1.437 \times f_x) \quad (7)$$

Therefore, finally, a linear relationship (Equation 8) can be developed for the total moisture content of a sand sample (M_t) with respect to total internal and surface pores (P), the density of water with respect to the temperature at testing (ρ_w) and shape and surface characteristics of sand particles developed above (Equations 6 & 7).

$$M_t = 3.7 + (P \times \rho_w) + (0.828 \times f_A) + (0.394 \times f_I) \quad (8)$$

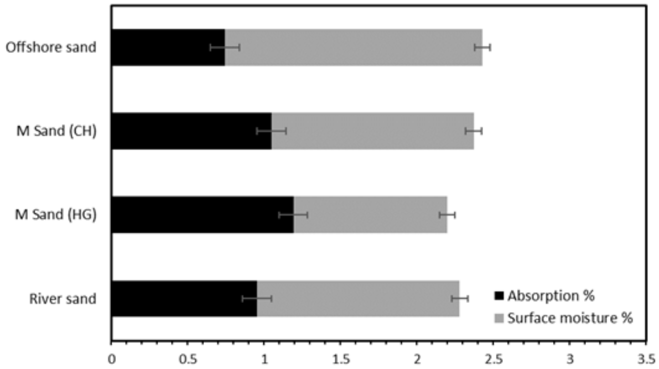

Fig. 11. Total moisture content

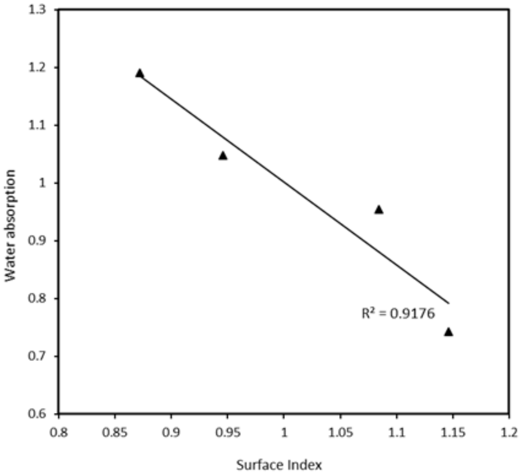

Fig. 12. Water absorption vs surface index

From Fig. 11, it can be observed that the water absorption capacities are increased with M Sand types than RS and OS. Absorption values are in the range from 0.743 % for OS to 1.191 % for MS(HG). Number of pores present in natural aggregates such as RS and OS are lower than manufactured aggregates where Hornblende-Gneiss and Charnockite rocks are available with internal and surface pores which can increase the absorption of water. This concept can be related to numerical values plotted in Fig. 11. However, increased surface moisture can be observed with RS (1.326 %) and OS (1.684 %) than MS(HG) (1.006 %) and MS(CH) (1.323 %). Angular size particles with rough texture can reduce the total surface area which is directly proportional to surface moisture and thus total moisture present in the sand. Round and smooth RS and OS particles increase total surface area which can be related with above mentioned higher surface moisture values. Moreover, the presence of fines can also affect the absorption of water. M Sand types contain more fine content than RS and OS which can also be taken as one of the causes for the increased water absorption. Another important parameter that can affect the batching of concrete and cement mortar mixes is bulking of sand. Bulking is termed as the ratio of increase in the total volume of moist fine aggregate and same mass in dry state. Volume increase due to moist occurs due to the surface tension forces acting between moisture and sand particles. Magnitude of such surface tension forces depends on the specific areas of sand particles. This study only deals with fine aggregate particles in the range of 4.75 mm to 0.075 mm. However, the variations in the presence of particles of individual size fractions can lead to different bulking values. From the gradation curves (refer Fig. 2), it can be observed that both MS(HG) and MS(CH) have higher percentages of particles in the range of 4.75 mm to 1.18 mm than RS and OS which highlights the coarseness of M Sand. So, surface tension acting between M Sand particles should be higher than RS and OS particles which tends to hold the particles apart and thus increase the overall volume of sand. This scenario is well distributed in Fig. 13. Curves are plotted with the increase in volume against the moisture added to the test sample where an optimum position is achieved by each sand type. This can be the maximum bulk that a sand type can attain with increasing moisture content. Due to the higher variations in bulking between M Sand and natural aggregates, concrete and cement mortar mixes with M Sand should be corrected more carefully with bulking of sand than mixes with RS and OS or blending M Sand with OS can reduce the problems with an increase in volume due to the moist present.

4.5 Hazardous Materials

Potentially harmful substances present in fine aggregate can deteriorate both concrete and cement mortar in fresh and hardened states. There are various types of hazardous materials such as fines (less than 0.075 mm), clay lumps and friable particles, silt, organic impurities, toxic minerals, lightweight and soft particles present in fine aggregate. RS extracted from river beds has the possibility of containing more clay, friable and silt particles while OS is dredged from deep-sea which can contain shell, salt and chloride contents. Other types such as MS(HG) and MS(CH) are manufactured by crushing Hornblende-Gneiss and Charnockite rocks through several stages. Therefore, each sand type considered here is having different harmful materials with varying sizes. To analyze this behavior the identification of some of the above potential materials was determined through a set of experiments mentioned under Section 3.2. Table 8 lists down the harmful materials observed from each test procedure and Fig. 14 shows visual inspection of silt contents of each sand type through settlement test. Clear supernatant can be observed with MS(HG) and MS(CH) due to the easy settlement of heavy particles and OS because of the low content of very finer particles. However, due to some possibility of very fine impurity particles, unclear supernatant was observed with RS even after the observation time. This section focuses on mainly three types of harmful substances: fines (less than 0.075 mm), clay lumps and friable particles and silt present in all sand types and additionally chloride and shell contents in OS which cause various threats to concrete and cement mortar. Fines present in sand act as a coating between sand particles and cement paste forms weaker bonds and also increases the water demand. Clay lumps and friable particles and silt affect both durability by introducing popouts and workability by absorbing mixing water. Chloride content in sand causes efflorescence and thus corrosion of reinforcement due to the larger sizes of shells highly affect the workability. When focusing on fines content in each sand types, both M Sand types show higher inclusions of fines while natural aggregates are with very low percentages. This is due to the crushing of rocks through several stages. ASTM C33 [7] set the limitation on maximum permissible materials finer than 0.075 mm for concrete subject to abrasion and other concrete types with natural aggregates as 3% and 5% respectively. For manufactured sand these limits are extended to 5% and 7%. Therefore, all materials considered here, can be used in concrete without any preparations. Regarding the contents of clay lumps and friable particles, all types show possible amounts present where the above standard mentions the tolerable limit as 3 %. Maximum permissible values for silt content is not included in the above standard, where each fine aggregate type has arrived with low silt percentages. In addition to the above chloride content of OS shows less than 0.01% where BS 882 [44] and CS3 [45] standards are provided with the limit range of 0.01% to 0.05%. All the potential materials mentioned in Table 8 are within the tolerable limits. Therefore, the selected materials can be used in both concrete and cement mortar unquestionably.

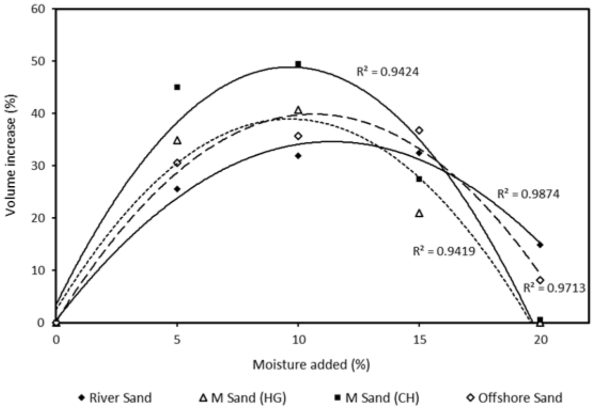

Fig. 13. Bulking of sand types

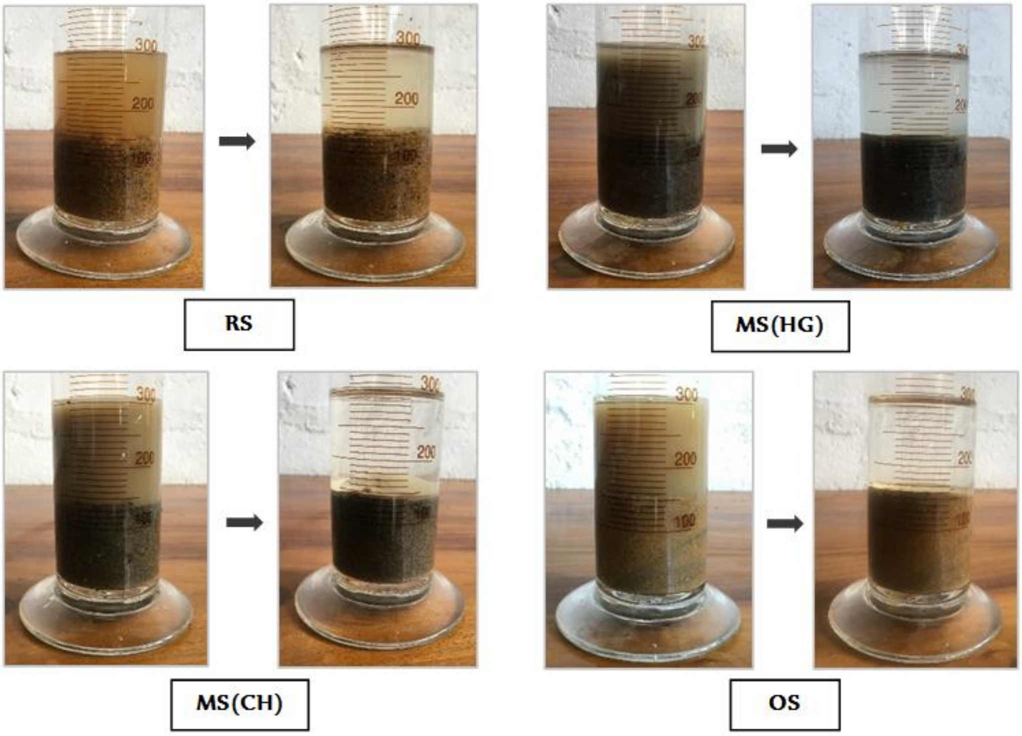

Fig. 14. Silt suspension in NaCl solution and settlement after 24 hours

Table 8. Potentially harmful materials

Sand code	Fines (< 0.075 mm) %	Clay and friable content %	Silt content %	Chloride content %	Salt content %	Shell content %
RS	0.18	1.59	0.29	-	<0.005	-
MS(HG)	6.28	0.77	2.88	-	-	-
MS(CH)	3.37	0.39	1.92	-	-	-
OS	0.24	1.18	0.95	< 0.01	0.016	7.45

5. CONCLUSION

The study on the suitability of blended sand for RS with physical, mechanical characterization and virtue concludes the following denouements:

- The main sand types used in this study can be categorized as natural aggregates (RS and OS) and purposely made aggregates (M Sand). Two types of M Sand considered here which are manufactured from two high-grade metamorphic rocks: Hornblende-Gneiss and Charnockite.
- Six different blended sand types are made by changing proportions of MS(HG) and MS(CH) with OS by mass from 25 % to 75 %.
- Color of selected sand types was changed from lighter (OS) to darker (M Sand). Because natural aggregates were formed very early and processed through a series of washing, while M Sand is produced instantaneously which enables the minerals present in the sand.
- Lower angularity numbers/indexes with natural aggregates and higher values with M Sand showed increased presence of angular particles in both M Sand types than RS and OS. Natural aggregates are said to be very smooth and M Sand particles have a rough texture where particle indexes range from 0.108 – 0.533 and 1.157 – 2.031 respectively.
- Total specific surface is increased with rounded and smooth texture particles where surface index values are varying from 1.078 of OS to 0.872 of MS(HG). A linear model is also developed for a total specific surface based on the combined effect of shape and texture of particles.
- To overcome the problems with workability and strength of mixes, blended sand with 25% to 75% replacements can be recommended with respect to the appearance of selected sand types.
- Gradation curve of RS particles greater than 0.075 mm lies within the required zone while M Sand and OS go beyond the limits for some particular sizes. Blending can effectively bring the curves into the required zone where 50 % replacement shows the perfect gradation curve for both M Sand types.
- All the selected sand and blended types fall within the category ‘well-graded sand’. Density of MS(HG) and MS(CH) are higher than RS and OS due to the higher inclusion of fines (less than 0.075 mm). Blending with OS replaces the number of fines and thus reduces the density of sand mix.
- Unit weight and void content of MS(HG) and MS(CH) are marginally higher than RS and OS as a result of heavy metamorphic rocks and particle shape and texture characteristics respectively. Blended sand of 25% replacement with OS shows better loose and packing densities next to M Sand types acting alone.
- Flowability shows a linear trend against blending levels, loose density, angularity, surface texture and total specific surface. But an optimum level of 50 % can be selected which shows similar behavior with RS.
- Higher water absorption capacities are noticed with M Sand types (1.1 – 1.2%) while RS and OS are arrived with 0.5 – 1.0% due to the increased total specific surface. However, the total moisture content of natural aggregates is slightly higher than M Sand.
- Fines content, clay lumps and friable particles and silt content of the selected sand types are within the maximum permissible limits. Therefore, these hazardous materials will not affect any of the blending proportions suggested in this study.
- When considering the overall behavior, blended sand types consisting of MS(HG) and MS(CH) with 50% OS can be

suggested as the optimum better performance sand mixes to be used effectively as the alternatives to RS.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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