Influence of Blended Fine Aggregates on the Performance of Lime - Cement Mortar – A Statistical Approach

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***Abstract*—This study investigates the performance evaluation of lime-cement mortar comprised of manufactured sand and offshore sand as the river sand alternatives. The most common mortars suggested by the standards such as S and N types were selected and five mixes were prepared for each type. Different sand compositions such as river sand alone, manufactured sand alone and blended sand with manufactured sand and offshore sand were used in the mixes. The performance of mortars with sand replacements were investigated based on the fresh and hardened properties. The experimental results were undergone for one-way analysis of variance (ANOVA) test to check whether the selected sand types and replacements statistically and significantly impacted the properties of mortar. Results revealed that the selected replacements statistically and significantly influenced the workability, compressive strength and flexural strength while no significant improvements were noticed with the workable life of mortars. Mortars with blended sand considerably improved the performance against capillary water absorption than mortar with river sand.**

Keywords—river sand, manufactured sand, blended sand, fine aggregate, lime-cement mortar

I. Introduction

Mortar plays a crucial role in the construction industry. It is one of the most utilized composite materials which is composed of binding agent, fine aggregate and water [1-2]. In addition to the cement type, water-to-cement ratio and environmental conditions, fine aggregate also influences the performance of mortar concerning workability, strength, durability, etc. The evolution of infrastructure developments has escalated the construction activities in most of the developing countries around the world. A study published by Global Construction Perspectives [3] in 2013 forecasted that the construction will result an output by more than 70% to $15 trillion worldwide by 2025. The recent survey implemented by Branavan and Konthesingha [4] in 2019 concluded that more than 90% of the construction works in Sri Lanka are still being operated using river sand as the primary fine aggregate.

Few literatures evinced the environmental drawbacks due to the increased river sand exploitation. Koehnken et al. [5] and Gavriletea [6] reported the adverse effects of river sand mining by correlating the types of extraction activities and effects on the most determining factors such as air, flora, fauna, water, soil and land. The publication made by Pereira and Ratnayake [7] explicated the negative consequences of river sand extraction in Sri Lanka by contemplating the depletion of the most common river basins. It is true that, still there is a gap on utilizing appropriate alternatives for fully replacing river sand (RS) to cease the sand mining. Considerable studies proved the possibilities of using manufactured sand (MS) and offshore sand (OS) alone for partially replacing RS in mortar. Here, the research done by Branavan et al. [8] can be considered as a supportive study which was executed on the cement mortars prepared with MS and OS. Due to the unavailability of studies on lime-cement mortars, the present work elucidates the applicability of blending MS and OS for completely replacing RS by incorporating the optimum replacement and blending levels achieved by the above supportive study.

II. Materials and Methods

A. Materials

A Portland Limestone Cement (PLC) classified under CEM II/A-LL 42.5 R of EN 197-1 was utilized as the primary binding material. A hydrated lime was used as the mineral admixture with a mass content of CaO + MgO as 93.23% (purity) according to EN 459-1. Four types of fine aggregates as shown in Fig. 1 were obtained: RS, MS made from Hornblende-Gneiss rock (MS(HG)), MS made from Charnockite rock (MS(CH)) and OS. The selected fine aggregates were undergone for particle size distribution test as per ASTM C136 and Fig. 2 represents the gradation curves of each fine aggregate with the upper and lower limits as defined in ASTM C144 to check the compatibility of these sand types for mortars.

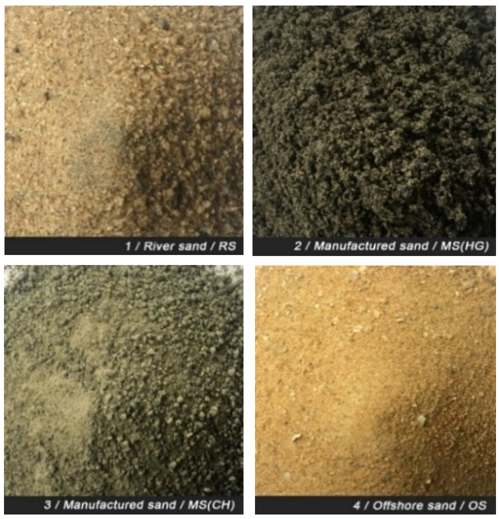

Fig. 1. Selected fine aggregates for the present study

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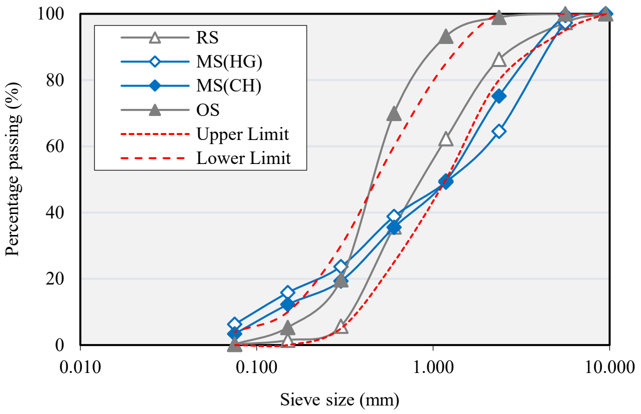

Fig. 2. Gradation curves of sands and conformity with ASTM C144

B. Mix design and experiments

Batching of aggregates were done at saturated surface dry (SSD) condition. The most common lime-cement-sand (l/c/s) ratios as mentioned in Table I were selected based on ASTM C270 and ICTAD SCA/4/1 standards. As explained in ASTM C270, the S and N types are widely applied lime-cement mortars in the interior and exterior masonry works that are exposed to low and high severity atmospheric conditions. These mortar types are also effective for load and non-load bearing appliances. This is the consequence for selecting these particular mortar types in the present study. RS100 is the reference mortar contained RS alone. MH100 and MC100 define the mortars made completely with MS(HG) and MS(CH) respectively. Mortars with blended fine aggregates such as BHO25/75 contained 25% MS(HG) and 75% OS and BCO75/25 included 75% MS(CH) and 25% OS. Here, these blending levels are considered the optimum ratios achieved by the supportive research [8].

All the mortar experiments were conducted based on ASTM and EN standards. Regarding the fresh properties of mortar; workability was tested according to EN 1015-3 and workable life was measured using EN 1015-9. The hardened properties such as compressive and flexural strengths were investigated based on EN 1015-11 and capillary water absorption was performed complying with ASTM C1403.

C. Method of analysis

A one-way analysis of variance (ANOVA) was used to determine whether there is any statistically significant effect on the properties of mortars due to the sand replacements. The one-way ANOVA was applied among each independent group of mortars with the selected sand contents (RS100, MH100, MC100, BHO25/75 and BCO75/25) to check the significance of differences between the mean values of properties. A null hypothesis was set as “there is no significant difference between the mean values” and the existence of the null hypothesis was checked at 95% confidence interval. This means when the *p*-value of the single factor ANOVA was less than 0.05, the null hypothesis was rejected and the alternative hypothesis was concluded. The rejection null hypothesis was also done when the *F*-value represented along with (degrees of freedom between groups, degrees of freedom within groups) was larger than the *F*-critical (*F* crit) resulted from ANOVA.

To determine which substitution level was significantly differed from the reference mix, a Tukey Kramer Post Hoc test was conducted at 95% confidence interval. Tukey’s critical value, Q_{crit} and the absolute mean difference between reference mortar and alternative mortar ($A\Delta$) were checked. The significance of the results was concluded as when $A\Delta > Q_{crit}$, the mortar made with the particular alternative had a statistically significant difference than reference mortar and vice versa.

The error bars provided in the figures represent the variance of the test results and the corresponding number of samples used for each mortar and test is mentioned in each figure.

D. Comparison of sand characteristics

Table II represents the comparison of selected fine aggregates. The most determining factors for the fresh and hardened properties mortar such as angularity index, surface roughness index and total specific surface index are concerned in addition to presence of microfine, void content and packing density.

As provided, it can be distinctly identified that the angularity of MS is higher than the RS. Similar comparisons were observed in the studies made by Shen et al. [9] and He et al. [10]. Above authors carried out an microscopical investigation to prove the more angularity of MS and it was then validated with the higher compressive strength of

TABLE II. SAND CHARACTERISTICS

Index	RS	MS(HG)	MS(CH)	OS
Angularity	1.753	1.907	1.906	1.739
Surface roughness	1.772	2.246	2.259	1.754
Total specific surface	1.084	0.872	0.946	1.146
Fine content (%)	0.180	6.280	3.370	0.240
Void content (%)	38.143	38.942	39.167	38.256
Packing density (kg/m^3)	1676	1915	1824	1658

TABLE I. MIX DESIGN OF MORTARS (KG/M^3) AND THE PERCENTAGE OF CORRESPONDING FINE AGGREGATES IN THE MIX

Type	Mortar nomenclature	l/c/s	Hydrated lime	PLC	Fine aggregate content (Percentage of Contribution)				Water
					RS	*MS(HG)*	*MS(CH)*	*OS*	
S mortar	RS100	0.5:1:4.5	186.29	525.00	1976.04 (100%)				262.50
	MH100					2028.44 (100%)			
	MC100						2020.95 (100%)		
	BHO25/75					507.11 (25%)		1498.87 (75%)	
	BCO75/25						1515.71 (75%)	499.62 (25%)	
N mortar	RS100	1:1:6	279.44	393.75	1976.04 (100%)				196.88
	MH100					2028.44 (100%)			
	MC100						2020.95 (100%)		
	BHO25/75					507.11 (25%)		1498.87 (75%)	
	BCO75/25						1515.71 (75%)	499.62 (25%)	

concrete. Beixing et al. [11] also concluded the greater surface roughness of MS than RS. In the particular literature, it was identified that the compressive and flexural strengths of concrete were linearly advanced with increasing roughness of MS. Moreover, Branavan et al. [12] briefly investigated few more properties such as flow ability, water absorption, degree of compactness, etc. of the same sand types concerned in this research.

III. Results and Discussion

A. Workability

As provided in Table III, a statistically significant effect on the workability was observed at 95% confidence interval. When individually investigating the mortars, except MH100 of S type ($A\Delta$=9.500 < Q_{crit} =6.891) others did not evince statistically significant differences than RS100. Among N mortars, MH100 ($A\Delta$=6.000 < Q_{crit} =5.316) and BCO75/25 ($A\Delta$=6.000 < Q_{crit} =5.316) revealed a statistically significant difference than RS100. Fig. 3 shows the variation of workability of S and N mortars. As shown, mortars with MS(CH) such as MC100 and BCO75/25 manifested similar or improved workability comparing with the RS100.

Mortars contained MS(HG) and MS(CH) alone revealed the lowest workability. This was purely due to the increased cubical shape and rougher texture of particles which was ended up with reduced lubricating effect between the particles and cement paste. Similar results can also be found in the literature [8,13]. The blended sand mortars slightly improved this property due to the inclusion of smooth and round OS particles which advanced the rolling effect.

B. Workable life

The replacement with alternatives did not prove a statistically significant effect at 95% confidence interval (see Table IV). Tukey Kramer Post Hoc test results increased Q_{crit} values for S mortar as 1.681 and N mortar as 1.607 than the $A\Delta$ of individual mortars. Here, all mortars lied within the ranges of 0.312 – 0.865 (S type) and 0.201 – 0.594 (N type).

Fig. 4 represents the penetration resistance of mortars at each time intervals considered. Mortars contained MS manifested the highest resistance to penetration while the blended sand mortars showed slightly lower resistance. As already predicted by Branavan et al. [8], here also the different particle shape and roughness marginally influenced the workable life of mortars. The more angularity and roughness of MS particles could increase the inter-particle locking and thus the resistance to penetration. The addition of OS slightly improved the lubricating effects which resulted in an improved workable life of mortars.

TABLE III. Results of ANOVA on Workability

Type	*F*-value (4,5)	*p*-value	*F* crit
S	11.940	0.009 (< 0.05)	5.192
N	17.440	0.003 (< 0.05)	5.192

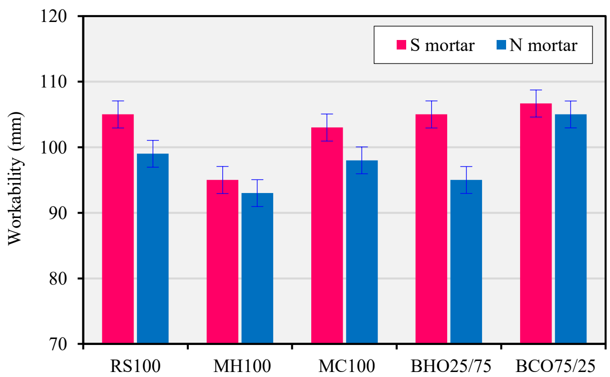

Fig. 3. Workability of mortars (No of samples per mortar – 2)

TABLE IV. Results of ANOVA on Workable Life

Type	*F*-value (4,20)	*p*-value	*F* crit
S	0.871	0.499 (> 0.05)	2.866
N	0.465	0.761 (>0.05)	0.761

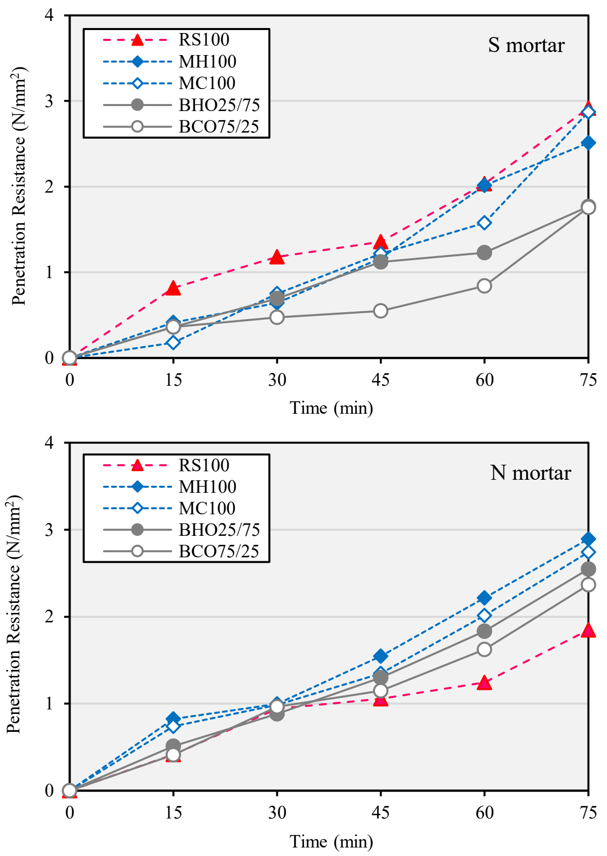

Fig. 4. Variation of penetration resistance of mortars with time

C. Compressive strength

At 95% confidence interval, the replacement with alternatives statistically and significantly improved the compressive strength of mortars at 2 and 28 days of curing (refer Table V). From the results of Tukey Kramer Post Hoc test, all S and N mortars at each curing age revealed a statistically significant difference from the reference mortar.

Fig. 5 illustrates the average compressive strength of mortars. It can be distinctly observed that MH100 and MC100 mortars of both types manifested an inflated strength. Due to the addition of 75% OS, the compressive strength of BHO25/75 was considerably decreased than RS100. However, BCO75/25 revealed slightly improved compressive strength and this was as a result of the dominance performance of MS.

With reference to the past literatures made by Shen et al. [9], He et al. [10], Beixing et al. [11] and Pavia and Toomey [14], the MS significantly increased the particle interlocking

TABLE V. RESULTS OF ANOVA ON COMPRESSIVE STRENGTH

Type	*F*-value (4,25)	*p*-value	*F* crit
S	162.188 (2 days)	1.71E-17 (< 0.05)	2.759
	254.834 (28 days)	7.23E-20 (< 0.05)	2.631
N	90.226 (2 days)	1.76E-14 (< 0.05)	2.441
	84.287 (28 days)	3.89E-14 (< 0.05)	2.984

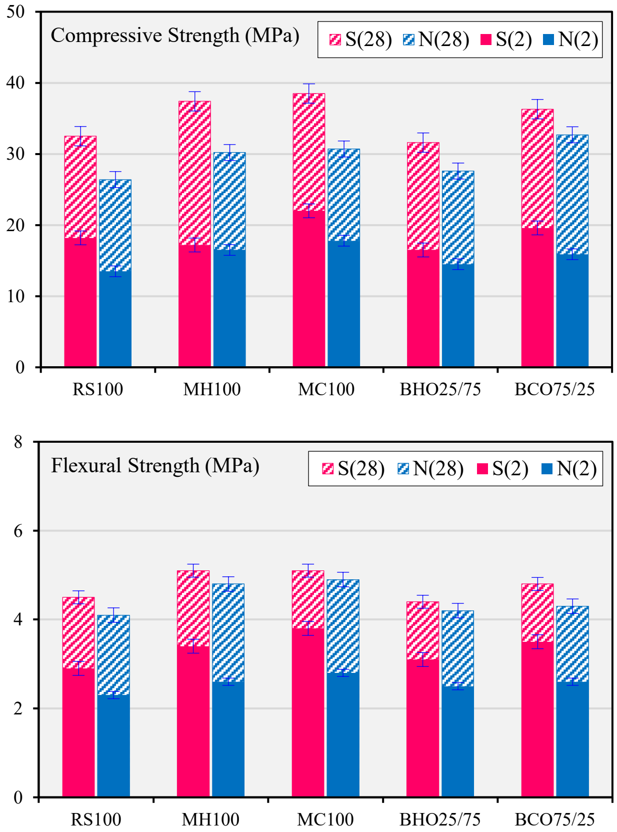

Fig. 5. Compressive and flexural strengths of mortars (No of samples per mortar – 3)

and slip resistance and thus advanced the resistance against external stress.

D. Flexural strength

The *p*-values of one-way ANOVA of 2- and 28-days flexural strength of mortars were less than 0.05 at 95% confidence interval (refer Table VI). This deduces that the sand replacements statistically and significantly impacted the flexural strength. As similar to the compressive strength, here also the Tukey Kramer Post Hoc test proved that each individual mortar statistically and significantly deviated from the reference mortar.

Fig. 5 also shows the average flexural strength of mortars. MH100 and MC100 mortars revealed the highest flexural strengths at the selected curing ages. The blended sand mortars such as BHO25/75 and BCO75/25 of both types exhibited marginally increased performance than RS100.

TABLE VI. RESULTS OF ANOVA ON FLEXURAL STRENGTH

Type	*F*-value (4,10)	*p*-value	*F* crit
S	34.559 (2 days)	7.91E-06 (< 0.05)	3.478
	8.069 (28 days)	0.004 (< 0.05)	3.154
N	8.536 (2 days)	0.002 (< 0.05)	3.441
	20.431 (28 days)	0.000 (< 0.05)	3.955

Based on the statistical analysis, it is true that the replacement of RS with alternatives and blending levels significantly influenced the compressive and flexural strengths of mortars. Here except the variation of sand characteristics, all other mix design and environmental factors were maintained constant throughout the study. Therefore, it should be discerned that the significant variation of strengths was solely depended on the fine aggregate characteristics. An attempt has been made in this research by correlating the above strengths of mortars with the angularity index (f_A) and surface roughness index (f_i) of fine aggregates. It should be noted that, when mortars included blended sands, the angularity and roughness indexes were determined based on the method suggested by Murdock [15].

Fig. 6 shows the influence of angularity of fine aggregates on the compressive and flexural strengths of mortars. Furthermore, a multiple linear regression analysis was done at 95% confidence interval with respect to the compressive strength, flexural strength, angularity index and roughness index as presented in Table VII.

Based on the analysis, the compressive and flexural strengths of mortars were linearly increased with higher angularity of sand particles. The rationale for this is the more angular particles could able to create better interlocking which may outcome a high strength of mortar with the assistance of advanced bonding between the cement paste and particles [9-11]. These effects can be clearly understood from the cement paste – aggregate diffusion models created by Ren et al. [16].

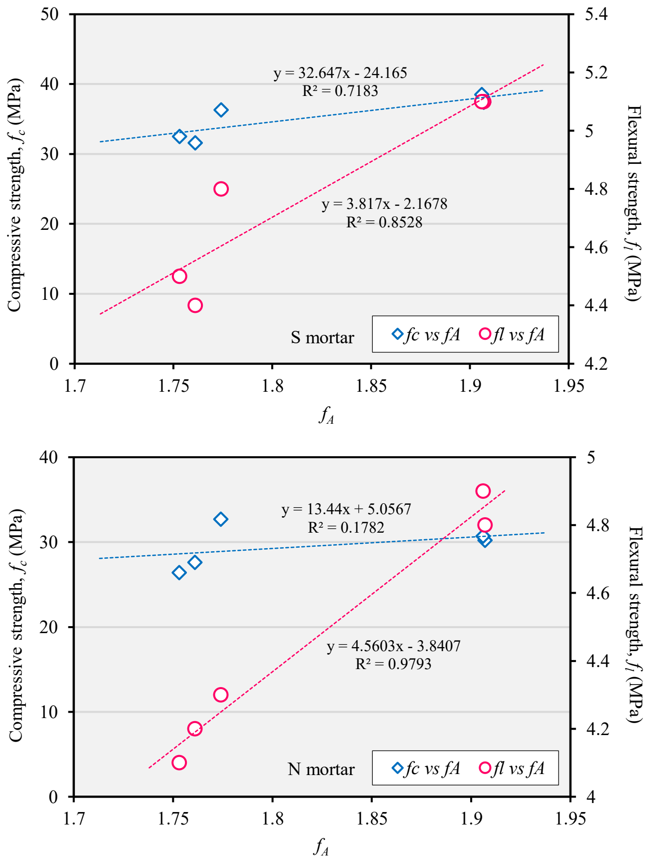

Fig. 6. Relationship between compressive strength, flexural strength and angularity index for S and N types

TABLE VII. LINEAR MODELS FOR STRENGTHS AND INDEXES

Linear model	S mortar	N mortar
$f_c = Xf_A + Yf_i + Z$	X = 2.255 Y = 7.786 Z = 16.25 R^2(adj.) = 0.5846	X = 4.262 Y = 2.351 Z = 17.261 R^2(adj.) = 0.6238
$f_l = \beta f_A + \mu f_i + \vartheta$	β = 1.0235 μ = 0.7157 ϑ = 1.5470 R^2(adj.) = 0.8142	β = 4.978 μ = -0.107 ϑ = -4.396 R^2(adj.) = 0.9605

A good linear correlation exists between the compressive strength of mortar, particle shape and surface roughness characteristics with acceptable adjusted R^2 values. Furthermore, the flexural strength of mortars was also highly influenced by the above particle physical characteristics which can be confirmed from the adjusted R^2 values.

E. Capillary water absorption

The capillary water absorption of mortars was investigated using a laboratory-scale uptake container complying with the standard. The absorption of mortar cube specimens were calculated at 0.25 h ± 0.5 min, 1 h ± 2 min, 4 h ± 10 min and 24 h ± 15 min from the immersion. Fig. 7 represents the variation of the capillary water absorption of S and N mortars with time. Statistical analysis of the capillary water absorption of mortars was done after 24 h ± 15 min of continous partial immersion in water which was the maximum capacity of the water absorption of mortars.

According to one-way ANOVA results as mentioned in Table VIII, the sand replacements did not statistically and significantly affect the water absorption of mortars at 95% confidence interval,. This can be clearly understood from the Tukey Kramer Post Hoc test where the mean difference (*AΔ*) of each mortar was lower than Q_{crit}. This reveals that there was no statistically significant difference between the alternative mortars and reference mortar.

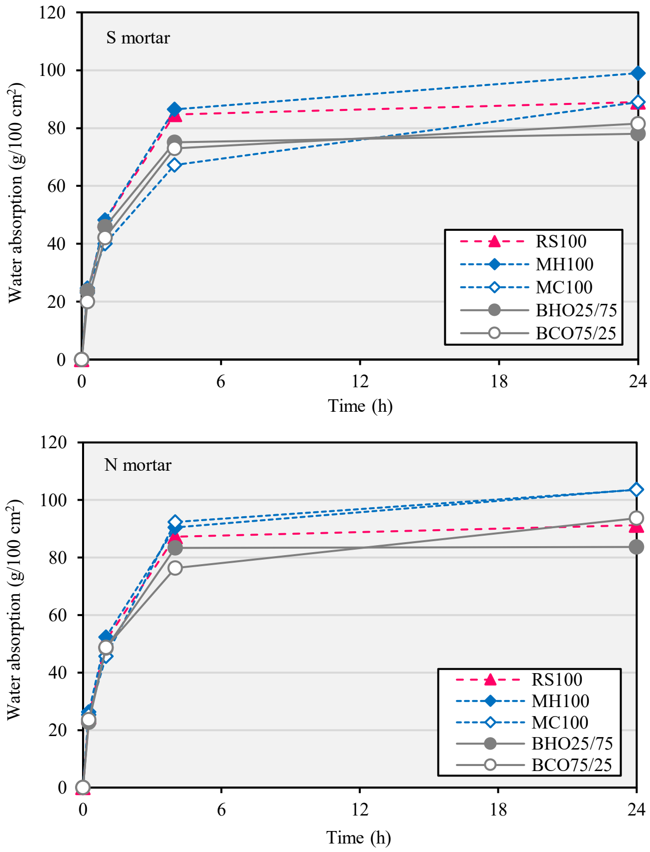

Fig. 7. Variation of capillary water absorption of mortars with time

TABLE VIII. RESULTS OF ANOVA ON CAPILLARY WATER ABSORPTION

Type	*F*-value (4,15)	*p*-value	*F* crit
S	0.083	0.986 (> 0.05)	0.986
N	0.051	0.995 (> 0.05)	0.995

Various constituents of fine aggregate could influence the total specific area including the micro fine content and particle size. When contemplating the micro fines, percentage of inclusion was varied as OS < RS < MS(CH) < MS(HG) [12]. Here, the maximum particle size of each sand type was 4.75 mm. It is clear that the presence of microfine played a major role on the varying total specific surface of hardened mortars. Fig. 8 exhibits the relationship between capillary water absorption of S and N mortars and total specific surface index of fine aggregates. The relationship between the above properties was arrived with an increasing polynomial trend with acceptable R-squared values for both mortar types.

The initial absorption rate of mortar depends on the total specific surface of specimen submerged in water. However, the long-term absorption is influenced by the internal porosity of mortar. Pavia and Toomey [14] proved the above statement where authors observed 35% increase in the capillary suction of mortars when low gradation fine aggregates were included. The water-contacted surface characteristics of a typical mortar type can be identified using Fig. 9 which are the processed images from ImageJ software. The enhanced images clearly exhibit the pores presented in the contacted area. Due to the increased micro-fine content in MS, the total specific surface and void content of MH100 and MC100 mortars were increased which resulted in higher water absorption. Mortars with blended sand such as BHO25/75 and BCO75/25 manifested reduced macro pores than RS100 mortar due to the higher packing density of MS and OS.

IV. CONCLUSIONS

This study was preformed to evaluate the applicability of blending manufactured sand with offshore sand as the alternative for river sand in lime-cement mortar. Ten mortar

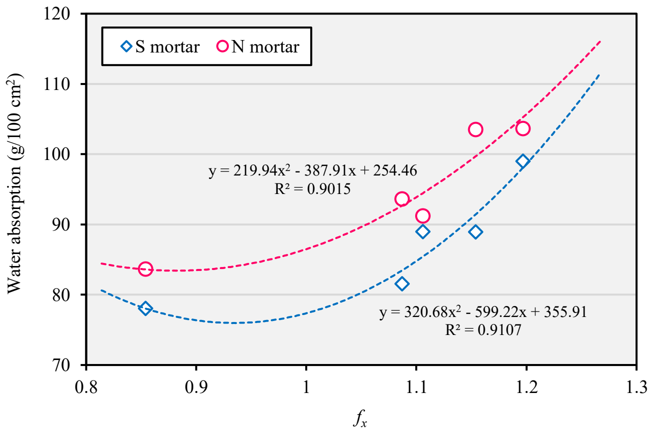

Fig. 8. Relationship between optimum capillary water absorption of mortars and total specific surface index of fine aggregates

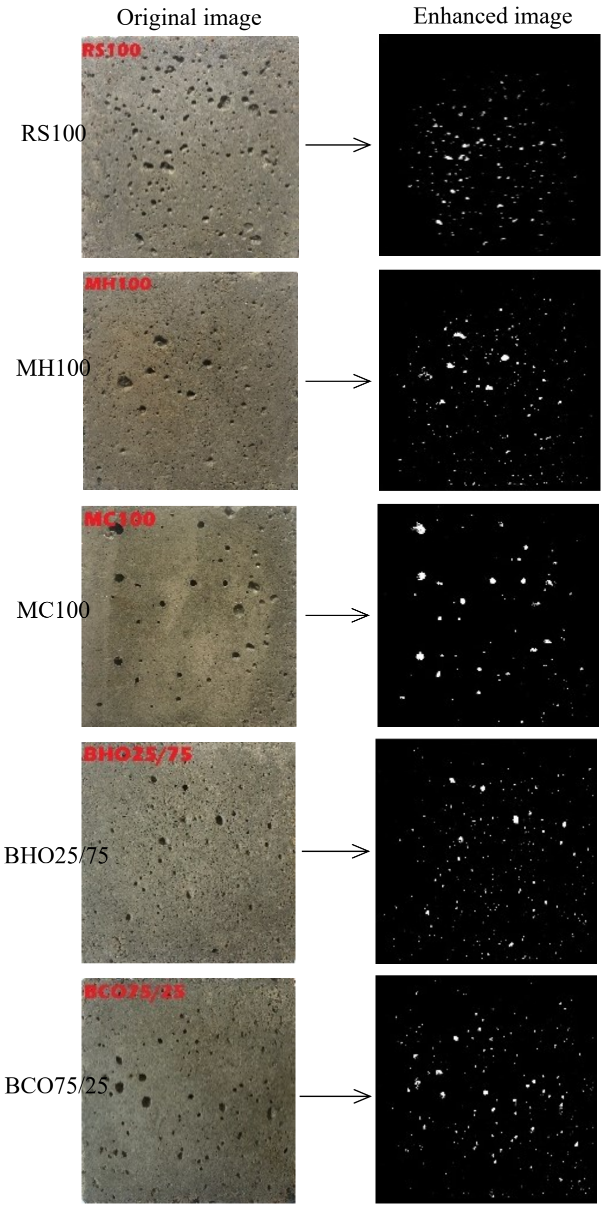

Fig. 9. ImageJ software processedimages of contacted mortar surfaces with water

mixes were prepared with varying fine aggregate content such as RS100, MH100, MC100, BHO25/75 and BCO75/25 considering two mortar types. A satistical approach has been done to check the significance of replacements which derives the following conclusions:

- The replacement with alternatives statistically and significantly affected the workability and strengths of mortars. While, no such impact was noticed with the workable life and capillary water absorption.
- The workability and workable life of MH100 and MC100 mortars were lower than RS100. However, when mortars incorporated blended sand, the above properties were improved to an extent.
- Highest compressive and flexural strengths were noticed with MH100 and MC100 mortars. BHO25/75 and BCO75/25 mortars also manifested improved performances than reference mortar.
- Comparing with other mortars, blended sand mortars revealed the lowest capillary water absorption which ensures the high durability.
- The angularity, surface roughness and total specific surface of fine aggregages significantly influenced the fresh and hardended properties of mortar.

Therefore, the blended sand with manufactured sand and offshore sand considered in this research are applicable as the effective alternatives in S and N mortars.

ACKNOWLEDGMENT

The authors wish to thank the National Building Research Organization, Sri Lanka for providing necessary supports for conducting the laboratory experiments. Authors also express their gratitude to INSEE - Siam City Cement, Sri Lanka for granting the required materials for this study.

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