STRENGTH AND DURABILITY STUDIES ON CONCRETE MADE WITH MANUFACTURED SAND

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ABSTRACT

Use of manufactured sand in concrete has been an area of interest for many researchers across the globe. The available limited natural sand is unable to meet the growing demand of fine aggregate for the needs of construction. It is proposed to compare the physical properties of natural river sand with manufactured sand (M-sand). The current study was conducted on the mixes M30, M40 and M50. The modulus of elasticity (MOE) was evaluated by changing the relative proportion of M-sand from 0 to 100%. Additionally, impact resistance tests and sorptivity tests were also conducted on the said mixes for the optimum proportion of the manufactured sand. Furthermore, the microscopic studies such as scanning electron microscopy (SEM) and electron dispersive spectrometry (EDS) were also conducted. Improvement in MOE and resistance to impact loading was observed with increase in grade of the mix. However, reduction in sorptivity was observed with increase in grade of concrete and the presence of M-sand. Moreover, a comparison was made between the experimental MOE values and those obtained from IS code. Microscopic studies revealed the presence of angular and rough surface of M-sand as compared to natural sand and it was fund to be the reason behind improvement in MOE and impact resistance and reduction in sorptivity.

Keywords: manufactured sand, modulus of elasticity, sorptivity, impact resistance, SEM.

1. INTRODUCTION

Concrete has been commonly used construction material for sustainable developments of the country. The increased use of concrete has created a huge demand for fine aggregate. However, the natural river sand has been used as fine aggregate for making concrete. Being a natural resource, the fine aggregate get depleted due to their use in making concrete. The use of natural river sand has been becoming very expensive due to limited availability and more associated transportation charges from the riverbed to the construction site or concrete batching plant. Moreover, removing the natural sand from riverbed affects the river course, water table levels in the vicinity and thereby environmental related issues. This cascading effect of exploiting natural river sand has attracted the attention of research community across the globe. One solution to address this problem is to use manufactured sand (M-sand) instead of natural river sand in making concrete. M-sand is obtained by crushing the natural granite stone in the vertical shaft Impact crushers and screening the output form the fine aggregates of size less than 4.75mm. Some studies has been reported the effect of M-sand on strength and durability properties of concrete. Some key relevant research findings are discussed below.

Patel and Pitroda [1] reported that the MOE reduced in the presence of fly ash as compared to control mix. It was reported that MOE reduced by 53.79% and 46.43% for concrete grades M25 and M40 respectively when the 40% of cement was replaced by the fly ash. Similar observation was made by Pitroda and Umrigar [2] when fly ash and hypo sludge were used as cementitious materials. It was concluded that the 40% level of replacement with cement with hypo sludge and fly ash by volume resulted decrease in MOE by 32.50% and 31.12% for M25 and M40 grade mixes respectively. Tilak and Reddy [3] studied the effect on MOE when natural aggregates were replaced by weathered aggregate. It was reported that the weathered aggregate had lower MOE and higher durability. It was concluded that weathered aggregates could be used as replacement to normal aggregate.

Karugu *et al*. [4] evaluated the mechanical properties of concrete by replacing the natural river sand with M-sand. The study replaced 20% of natural river sand with M-sand. It was reported that a slight increase in MOE from 22 kN/mm^2 to 23 kN/mm^2 was observed. In addition, improvement in other mechanical properties was also reported. Furthermore, Lokeshwaran and Natarajan [5] reported that improvement in dynamic MOE was observed when M-sand was used in the place of natural river sand. Moreover, Shanmugapriya *et al*. [6] observed an improvement of MOE in the range of 3.80% to 7.30% when natural sand was replaced by M-sand by 0%, 20%, 40%, 60%, 80%, and 100%. Magudeswaran and Easwaramurth [7] reported that the MOE of HPC mixes were improved marginally when M-sand was used. Moreover, it was reported that MOE improved by 2.50% - 10% when silica fume was also added.

Solanki and Pitroda [8] reported that MOE reduced by 36.72% and 35.18% when 40% of the cement was replaced by hypo sludge for M25 and M40 grade concrete respectively. Liu *et al*. [9] revaluated the influence of steel fibres on impact strength of silica fume blended concrete. It was reported that number of blows were improved by 4 and 18 times for initial crack and fracture respectively when steel fibres were added. Abhinav and Rao [10] evaluated the impact strength of steel fibre reinforced concrete. It was reported that the addition of steel fibres improved the resistance to initial and final cracking.

In the present study, proportion of M-sand was changed from 0 to 100% for M30, M40 and M50 grade concrete and MOE was evaluated. Additionally, impact resistance and sorptivity behaviour was studied in the presence of M-sand. Furthermore, microscopic studies such as SEM and EDS were also conducted to understand the role of M-sand in concrete.

2. EXPERIMENTAL PROGRAM

2.1 Materials

Materials used for the current experimental study along with the relevant properties are mentioned below.

2.1.1 Cement

The ordinary portland cement (OPC) of grade 53 confirming to IS 12269 - 1987 was used for the experimental work (10). The properties of the OPC used are presented in Table No.1

2.1.2 Coarse aggregates

Aggregates were obtained by the crushing the locally available granite stone. Maximum size of the aggregate was limited to 20 mm. The aggregates of size 20 mm and 12.50 mm were blended in the study. The aggregates were confirmed to IS 389-1989 (11). The physical properties of the coarse aggregates are presented in Table-2.

Table-1. Physical properties of cement.

Property	Value
Specific gravity	3.15
Initial setting time	33 min.
Final setting time	385 min.
Fineness m^2 / Kg.	270.80
Soundness	1.00 mm
Standard consistency	31%
Compressive strength 7 days	43.50 MPa
Compressive strength 28 days	MPa

2.1.3 Fine aggregates

Locally available natural sand was used as fine aggregate. The fine aggregate used was confirmed to IS 389-1989. The physical properties calculated are presented in Table-2. Locally available granite boulders were used to obtain the artificial sand. The granite boulders were fed into the crusher and output was thoroughly screened to the required size and shape to eliminate the unwanted micro-fines. Then the screened fine aggregate was washed with water to obtain clean M-sand. SRC M-sand, which was manufactured at Salem, was used for the experimental investigation. The physical properties of manufactured sand were evaluated and are presented in Table-2. It was found form the sieve analysis that both natural river sand and M-sand were in zone-II.

Table-2. Physical properties of coarse aggregate and fine aggregates.

Property	Coarse aggregate	Fine aggregate	
		River sand	M-sand
Specific gravity	2.70	2.60	2.45
Bulk density (kg/m^3)	1510	1460	1556
Water absorption (%)	0.45	1.15	1.00
Moisture content (%)	0.85	1.10	1.15
Aggregate impact value (%)	12.50	-	-
Fineness modules	6.67	3.44	3.54
Fineness particles Less than 150mm (%)	-	4.14	5.30

2.1.4 Superplasticizer

Superplasticizer (SP) was used to improve the workability of concrete. CERAPLAST 300 RS (G) was used as superplaticizer for the experimental work. The SP was obtained from Cera Chem (PVT) ltd, Chennai and it is confirmed to ASTM C-494(12) and IS 9103-1999(13). The dosage of SP was fixed at 1% by weight of cement.

2.1.5 Water

Potable water free from suspended particles, organic and inorganic impurities, and confirming to IS 456-2000(14) was used for making concrete specimens and curing the concrete specimens as well.

2.2 Mix proportion

Concrete mixes M30, M40 and M50 grades were designed in accordance with the specifications laid down in IS: 10262-2009(15) and IS: 456-2000 (16). Mix proportions developed and w/c ratio used for control mix and the mix with 100% M-sand replacement are shown in Table-3.

Table-3. Mix proportions and w/c ratio for various grades.

Mix ID	M30		M40		M50	
	Mix proportion	**w/c ratio**	**Mix proportion**	**w/c ratio**	**Mix proportion**	**w/c ratio**
M1	1:2:3.53	0.45	1:1.69:3.13	0.40	1:1.54:2.97	0.35
M11	1:1.88:3.53	0.45	1:1.6:3.13	0.40	1:1.45:2.97	0.35

The relative proportion of natural river sand was varied from 100% to 0% and that of M-sand was changed from 0% to 100%. For each relative proportion of river sand and M-sand, a separate mix design was done to obtain the quantities of various ingredients to make the concrete. Weighted average of the natural river sand and M-sand was used based on their relative proportions in the mix.

2.3 Test methodology

2.3.1 Modulus of elasticity

Cylindrical moulds of size 150 mm dia and 300 mm length were used. After casting the samples, the concrete specimen samples were kept in the moulds for 24 hours. The specimens were removed form the moulds after 24 hours and cured in the water tank for 28 days. Before the specimen was taken for the test, the specimen was kept in open atmosphere for 2-3 hours before testing. Dial gauge was fixed such a way that the gauge points were symmetrical about the centre of the specimen. The load was applied continuously at the rate of 140 Kg/cm^2/minute till an average stress of (C+5) Kg/cm^2 was reached, where 'C' is the average compressive strength of the cubes evaluated to the nearest 5 Kg/cm^2. The load was maintained at least one minute at this stress and was reduced gradually at an average stress of 1.5 Kg / cm^2 and the reading was taken. The load was again applied at the same rate until an average stress of (C +1.5) Kg/cm^2 was reached and the compressometer reading was noted. The load was gradually reduced to 1.5 Kg / cm^2 and the reading was noted down. The load was applied for the third time and the extensometer readings were taken.

Figure-1. Experimental set-up for modulus of elasticity test.

The strains at the various loads in the last two cycles were calculated separately for each extensometer and the results were plotted graphically against the stress. Straight lines were drawn through the points for each extensometer. The slopes of these two lines were determined and the average value was reported. The experimental set-up used for the study is shown in Figure-1.

2.3.2 Impact resistance

The impact test was performed in accordance with the impact testing procedures recommended by ACI Committee 544. The test was carried out by dropping a hammer weighing 44.7N (10 lb) from a height of 457mm (18 inch) repeatedly on a 64mm (2.5 inch) hardened steel ball, which was placed on the top of the centre of the cylindrical specimen (disc) as shown in Figure-2. The test was continued until failure. For each specimen, number of blows for initial crack and final crack were recorded. The former value measures the number of blows required to initiate a visible crack, whereas the latter measures the number of blows required to initiate and propagate cracks until ultimate failure. According to the ACI committee, the ultimate failure occurs when sufficient impact energy has been supplied to spread the cracks enough so that the test specimen touches the steel legs.

Figure-2. Experimental set-up for drop-weight test.

2.3.3 Sorptivity

Cylindrical specimens of size 100 mm x 50 mm were cast to determine the sorptivity as per ASTM C 1585-04. The specimens were cured in water for 28 days. Concrete specimens were oven-dried at a temperature of 50 $\pm$ 2 ^oC for 3 days. After 3 days, the specimens were placed in sealable container for 15 days. Precautions were taken to allow free flow of air around the specimen by ensuring minimal contact of the specimen with the walls of the container. After 15 days, the weights of the specimens were recorded and sides were sealed. Average diameter of the specimen was measured and top surface was also sealed. The specimens were placed in water and stopwatch was started. The mass of specimen was recorded at interval 1 min, 5 min, 10 min, 20 min, 30 min, 1 hr, 2 hr, 3 hr, 4 hr, 5 hr, 6 hr, 1 day, 2 days, 3 days, 4 days, 5 days, 6 days, 7 days and 8 days. Initial rate of absorption and Secondary rate of absorption were computed from the experimental study. Test set-up used for the experimental study is shown in Figure-3.

Figure-3. Test set-up for sorptivity test.

2.3.4 Microscopic studies

Scanning electron microscopy (SEM) and electron dispersive spectrometry (EDS) were conducted on the specimens made with natural river sand and on the specimens made with M-sand separately.

3. RESULT AND DISCUSSIONS

3.1 Modulus of elasticity

From the Table-4 it is evident that increase in proportion of M-sand enhanced the MOE until mix M8, which had 30% proportion of river sand and 70% proportion of M-sand. Further addition of M-sand showed adverse effect on the MOE of concrete. Additionally, it can be observed that more MOE was observed for the same mix with the increase in grade of concrete. Figure-4 shows the variation of MOE of various mixes. It can be observed from the figure that although more gap in performance between M30 and M40 was observed in MOE, less gap in the performance of MOE was observed for the mixes M40 and M50. A maximum increase of about 11%, 10% and 12% in MOE was observed for M30, M40 and M50 grade concrete respectively.

Table-4. Modulus of elasticity test results.

Mix	**Modulus of elasticity** (GPa)		
	M30	**M40**	**M50**
M1	33.10	39.40	39.90
M2	33.50	39.80	41.20
M3	33.80	39.80	41.40
M4	34.20	39.90	41.80
M5	34.80	41.20	42.00
M6	35.50	41.40	42.80
M7	36.00	41.80	43.60
M8	36.40	43.20	44.80
M9	36.80	42.20	43.00
M10	35.50	41.80	42.80
M11	35.00	41.20	42.60

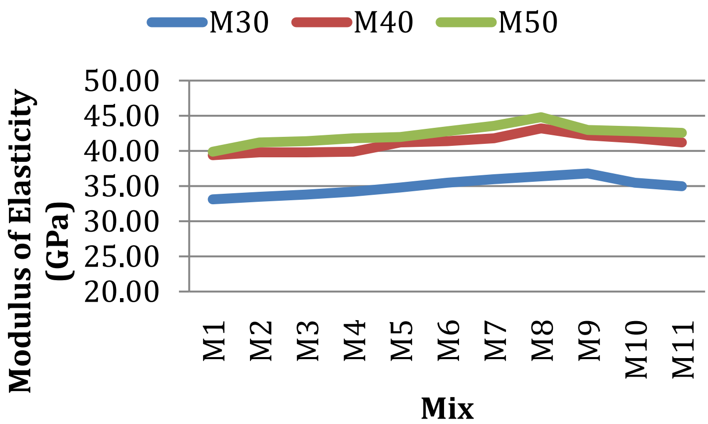

Figure-4. Modulus of elasticity test results.

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MOE for various mixes and grades were also computed using the relationship suggested by IS: 456-2000. Figure-5 shows the values of MOE obtained from the experimental study and those computed for Indian standard codal provisions for M30 grade concrete. Similar analysis was carried out for M40 and M50 as well. It was found from the analysis that IS code provides the conservative MOE values for concrete made with M-sand. In other words, the actual MOE values are higher than those obtained from IS code. Though a perfect correlation was observed between the compressive strength and MOE based on the equation suggested by IS code, such correlation could not be observed for MOE values obtained experimentally.

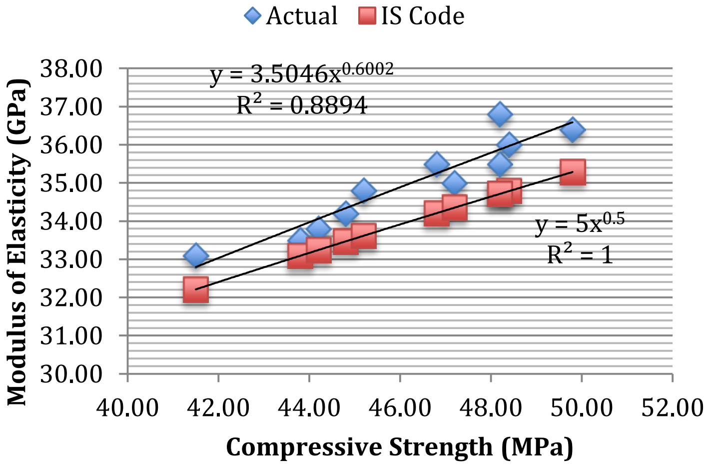

Figure-5. MOE based on experimental and IS code for M30.

3.2 Impact resistance

Number of blows the specimens took for the initial crack and the final crack is presented in Table-5. At a glance it is evident that increase in grade of concrete offered more resistance to impact loading for the same relative proportion of the river sand and the M-sand. It was observed that the specimen that took more number of blows for initial crack took more number of blows for final crack as well.

Table-5. Impact resistance of various mix proportions.

Mix	No. of blows	
	First crack	Rupture
M30-M1	45	99
M30-M8	51	116
M30-M11	49	112
M40-M1	98	135
M40-M8	109	147
M40-M11	107	143
M50-M1	104	145
M50-M8	124	154
M50-M11	121	147

Figure-6 shows the comparative performance of specimens in resiting the impact loads for the initial crack and the final crack. The mix M50-M8 offered maximum resistance to cracks followed by M50-M11. The results indicate that the impact resistance of M40 grade concrete was almost twice that of M30 grade concrete in resisting initial crack. It was observed that the presence of M-sand offered more resistance in developing the cracks on application of impact load. Additionally, it was observed that M8 specimen, which had both river sand and M-sand showed superior performance as compared to control mix and the mix with 100% M-sand.

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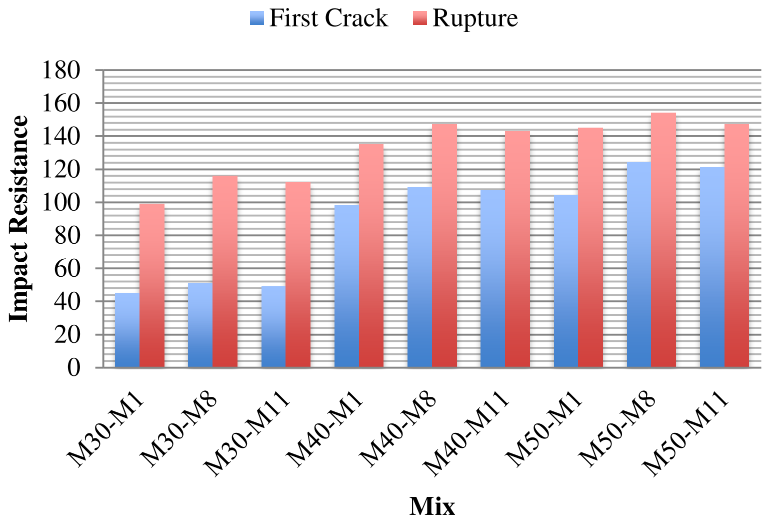

Figure-6. Impact resistance of various mix proportions.

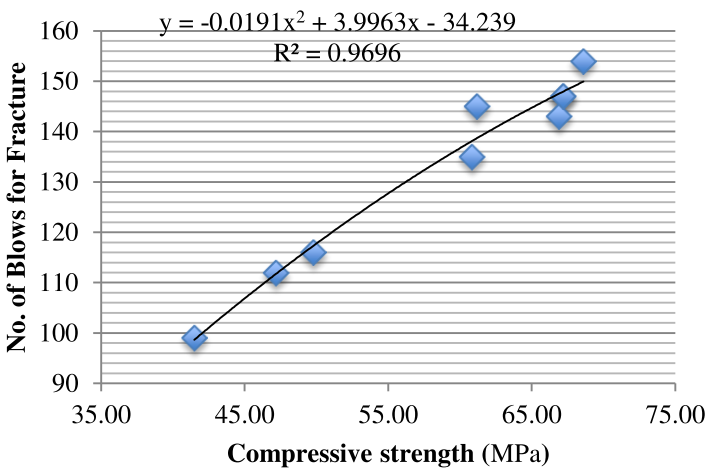

Figure-7. Compressive strength and impact resistance.

A regression analysis, as shown in Figure-7, was performed to verify the relation between the compressive strength and the impact resistance for final crack. A strong correlation with R^2 value of 0.97 was observed. It indicates that compressive strength has strong proportionate relation with impact resistance for final crack.

3.3 Sorptivity

The performance of various concrete specimens in water absorption capability in unilateral direction is shown in Table-6. The cumulative weight of water absorbed during various time periods were measured and graphs were plotted to obtain the initial rate of Absorption (IRA) and secondary rate of absorption (SRA). It was observed that higher-grade concrete showed lower IRA and SRA for the same proportions of the river sand and the M-sand. Additionally, it was noticed that IRA and SRA values reduced with the increase in proportion of M-sand.

Table-6. Sorptivity test results.

Mix	**IRA** (10^{-4} mm/$S^{0.5}$)	**SRA** (10^{-4} mm/$S^{0.5}$)
M30-M1	0.8495	0.1110
M30-M8	0.4247	0.0615
M30-M11	0.3189	0.0552
M40-M1	0.7436	0.0955
M40-M8	0.4247	0.0569
M40-M11	0.2863	0.0500
M50-M1	0.6365	0.0878
M50-M8	0.3769	0.0536
M50-M11	0.2556	0.0471

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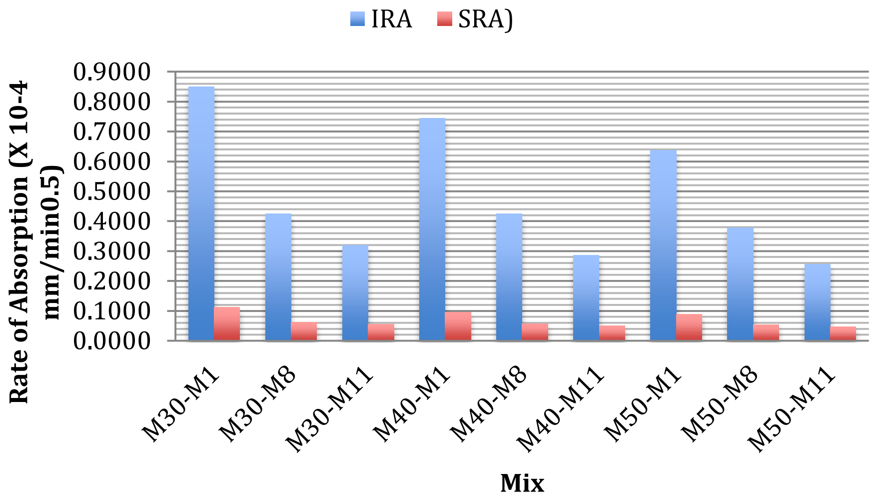


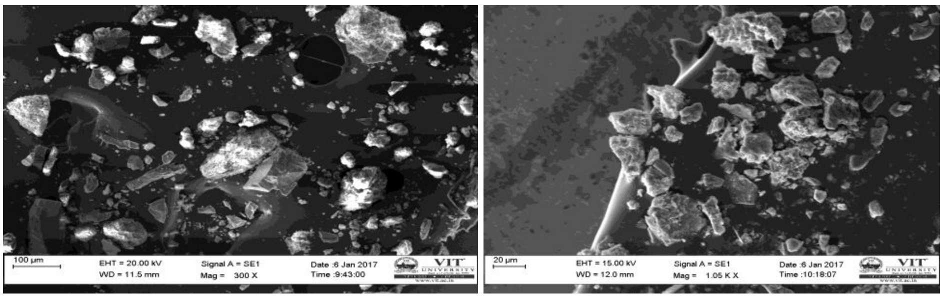
Figure-8. Sorptivity test results.

Figure-8 shows the graphical representation of the performance of various specimens in the sorptivity test. It can be noticed that the SRA is much lower than IRA for all mix proportions. Additionally, it was noticed that the control mix exhibited more rate of absorption irrespective of the grade of concrete.

3.4 Microscopic studies

SEM analysis provided the key information about the superior performance concrete made with M-sand as compared to the control mix. Figure-9 shows the SEM images of the M-sand and the natural river sand. It was observed that the M-sand had elongated and rough structure as compared to round and smooth surface of river sand. The rough and elongated structure of M-sand helped reducing the micro-cracks in the vicinity of interfacial transition zone (ITZ). Thus, a strong bond between the cement matrix and the M-sand at ITZ was noticed as compared to that was observed in case of river sand.

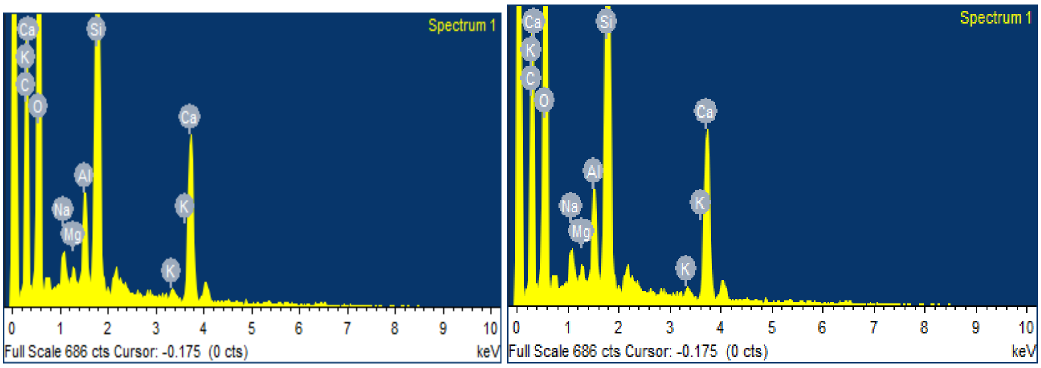
The slight increase in MOE was attributed to strong ITZ when M-sand was added. Strong bond between the cement matrix and the M-sand was main reason the improvement in impact resistance. The strong bond took more number of blows for propagating the cracks to the top surface and showing the complete fracture of the specimen. Strong bond at the ITZ could be the main reason for reduction in IRA and SRA when M-sand was added.



(a) (b)

Figure-9. SEM images of (a) M-sand (b) River sand.

Figure-10 shows the elements present in M-sand and natural river sand. The EDS analysis showed that both the M-sand and river sand have same elements in approximately at the same proportion.



(a) (b)

Figure-10. EDS images of (a) M-sand (b) River sand.

4. CONCLUSIONS

Experimental tests conducted in the presence of and absence of M-sand has given us insights about the performance of M-sand in concrete. Following conclusions can be drawn from the experimental study.

- A weighted average method based on the specific gravity of the river sand and the M-sand was introduced to mix design of concrete using M-sand as partial and full replacement of cement.
- MOE slightly improved with the presence of M-sand. A relative proportion of 30% Natural River sand and 70% of M-sand resulted better MOE as compared to other proportions.
- Presence of M-sand affected the impact resistance of concrete positively. M8 mix showed superior performance as compared to control and M11 mixes.
- The addition of M-sand reduced the rate of absorption of water as compared to control mix.
- SEM analysis revealed that M-sand has elongated and rough surface texture as compared to round and smooth texture of river sand. This structure of M-sand was believed to be responsible for improvement in studied parameters.
- EDS analysis confirmed no major change in elements present in the river sand and the M-sand.

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