Research Article

Properties and microstructure of concrete using pozzolanic materials and manufactured sand as partial replacement of fine aggregate

Kiran M. Mane[1] · **D. K. Kulkarni**[2] · **K. B. Prakash**[3]

Abstract

The overuse level of cement and natural sand for civil industry has several undesirable social and ecological consequences. As an answer for this, industrial wastes called as by-products (pozzolanic materials) such as fly ash, GGBFS, silica fume and metakaolin can be used to interchange partially cement and natural sand by manufacturing sand (M-sand). In this paper, the detailed experimental investigation was done to study the effect of partial replacement of, natural sand by M-sand in various percentages (0%,10%, 20%, 30%, 40%, 50%, 60%, 70%, 80%, 90% and 100%), with water–cement ratio of 0.45 and cement was partially substituted by 20% of pozzolanic materials. M30 grade of concrete mix proportions were designed as per IS 10262:2009 guidelines. The fresh concrete properties and tensile strength results, were checked for the different concrete mix proportions and compared with conventional concrete. The tests on hardened concrete were destructive in nature which includes tensile test on cylinder as per IS: 5816-1999 at 28 days of curing. From this research work, it can be concluded that for replacement of 60% natural sand by M-sand and 20% cement by silica fume yields maximum tensile strength and improves the microstructure than conventional concrete.

Keywords Pozzolanic materials · M-sand · Workability · Tensile strength · Microstructure · X-RD · EDS

1 Introduction

Concrete was the most widely used construction material throughout the world. Hence concrete technology was the backbone of the infrastructural development of every country. It has made tremendous advancements in the western as well the eastern world. Annual worldwide manufacture of concrete was approximately 1 m^3 per person on earth. The main component of concrete was associated with Portland cement. The global cement production was about 2.6 billion tonnes in 2008. By 2020, cement requirement was estimated to be around 3.5 billion tonnes this would obviously cause an equal demand on the materials like sand, aggregate and other materials required to produce huge quantity of cement concrete [1]. This would naturally cause depletion of all the natural resources connected in making cement concrete every year. The three major concerns associated with cement production are enviro-eco issues, sustainability issues and intense energy needs [2]. The production of cement releases approximately an equal amount of CO_2 into atmosphere due to the calcination of limestone and combustion of fossil fuel. In view of this, with an interest in minimizing the overall CO_2 emissions associated with OPC composites blended cements were introduced by partially replacing OPC by pozzolanic materials such as fly ash, ground granulated blast furnace slag (GGBS), silica fume, metakaolin, rice husk ash etc. [3]. Also due to increased levels of construction expected in the forthcoming years, it was expected that fine aggregates suitable for use in concrete would become

✉ Kiran M. Mane, kiranmane818@gmail.com; D. K. Kulkarni, dilipkkulkarni@rediffmail.com; K. B. Prakash, kbprakash04@rediffmail.com | [1]S.D.M. College of Engineering and Technology, Dharwad, Karanataka 580 002, India. [2]Department of Civil Engineering, S.D.M. College of Engineering and Technology, Dharwad, Karanataka 580 002, India. [3]Government Engineering College, Haveri, Devagiri, Karanataka 581 110, India.

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scarce or uneconomical [4]. With the expected shortfall in natural sands, manufactured sands offer a viable alternative to natural sand. Manufactured sand had to satisfy the technical requisites like workability and strength of concrete. Since the data on this aspect of concrete using manufactured sand is scarce, it is necessary to investigate the concrete produced with manufactured sand [5]. Akshay et al. [6] where studied the review of the different alternatives to natural sand in preparation of mortar and concrete. The review study reveals that the using different alternatives for river sand produce better results than conventional concrete. Madheswaran et al. [7] where studied the concrete properties with two water cement ratio and different proportion of copper slag ranging 0–100% of fine aggregate. Finally study reveals that copper slag provides better performance in workability and strength aspect. An et al. [8] where studied the effect of the type and mineralogy of fine and coarse aggregates in the normal strength concrete properties. The study concluded that specimens with higher coefficient of thermal expansion (CTE) are more susceptible to thermal stress. Weiguo et al. [9] where studied the several experiment on influence of manufactured sand characteristics on manufactured sand concrete performance. Results indicated that the particle shape of manufactured sand had little influence on the performance of its concrete, while the stone powder of manufactured sand had more remarkable influence on its concrete performance. Cortes et al. [10]. where studied the mechanical performance of mortar for different water cement and fine aggregate to cement ratios. The study reveals that adequate flow and compressive strength were attained when the volume of paste exceeded the volume of voids in the loosely packed aggregate. Maghashree et al. [11]. where studied the suitability of manufactured sand by conducting the tests related to physical properties of fine aggregate. Study reveals that the manufactured sand can be used as an alternative for natural sand which maintains the eco balance. Ilangovana et al. [12] studied the feasibility of the usage of quarry rock dust as hundred percent substitutes for natural Sand in concrete. Finally study reveals that the compressive, flexural strength and durability studies of concrete made of quarry rock dust are nearly 10% more than the conventional concrete. Kalirajan and Vishnuram [13] where studied the fresh and hardened properties of self compacting concrete using manufactured sand. The study concluded that the performance of SCC with manufactured sand in the plastic and hardened state is comparable and satisfies the requirement. Adams et al. [14] where studied the effect of manufactured sand on properties of high performance concrete. The study concluded that 50% replacement of fine aggregate by M-Sand give maximum result in strength and durability aspects.

From above literature review it is observed that most of the investigation are addressed the strength issue of concrete. Most of the work is limited to study tensile strength and microstructures of concrete made by using pozzolanic materials and partial replacement of natural sand by manufactured sand. Keeping this in mind, study of tensile strength and microstructure of concrete made by using pozzolanic materials and partial replacement of natural sand by manufactured sand is planed.

2 Materials and methodology

- OPC 43 grade cement and satisfy the requirement of IS 8112-2013 with specific gravity 3.15.
- Potable water is used for concrete mixing and curing.
- Locally available natural sand conforming to zone II with specific gravity 2.61 and fineness modulus 2.24 [15, 17].
- Locally available vertical shaft impact (VSI) crusher sand conforming zone II with specific gravity 2.82 and fineness modulus 2.91 [16]. Sieve analysis of natural sand and manufactured sand shown in Table 1.
- Coarse aggregates used in the experimental study are 10 mm and 20 mm size and having specific gravity 2.94 [17],
- Fly ash used in this experimentation was obtained from JSW plant Ratnagiri Maharastra India, having 58.54% silicon dioxide (SiO_2), specific gravity 2.1515 and 4.59% calcium oxide (CaO), classified as class F [18].
- Silica flume is obtained from ELKEM South Asia Pvt Limited Mumbai India was named Elkem-micro silica 920 D conforming to ASTM C1240. It is available in dry densified form and having 91.14% silicon dioxide (SiO_2), Specific gravity found 2.2 [19],
- Ground granulated blast furnace slag (GGBFS) is obtained from JSW plant Bellary Karnataka India having 41.61% silicon dioxide (SiO_2), specific gravity 2.85 [20].

Table 1 Sieve analysis of fine aggregates

Sieve designation	Percentage passing		Grading limit for zone II sand
	Natural sand	Manufactured sand	
4.75 mm	93.8	93.7	90–100
2.36 mm	85.2	83.3	75–100
1.18 mm	75.7	70.6	55–90
600 micron	42.3	43.4	35–59
300 micron	15.1	12.9	8–30
150 micron	6.9	5.1	0–20

- Metakaolin is obtained from Golden Micro Chemicals Mumbai, India having 54.66% silicon dioxide (SiO_2), specific gravity 2.2.
- Naphthalene based, free from chloride admixture used in this project was Fosroc Conplast SP430 to improve workability of concrete.

The experimental investigation was based on a reference concrete mix of grade M30 using natural aggregates. On the basis of the material properties, the proportioning of concrete mix was carried out in accordance to IS 456:2000 [21] and as per the guidelines of IS 10262:2009 [22].

3 Preparation of specimens

The concrete was produced by replacing natural sand by manufactured sand. The natural sand was replaced by manufactured sand in the proportion of 0%, 10%, 20%, 30%, 40%, 50%, 60%, 70%, 80%, 90% and 100%. Along with natural sand, 20% of the cement was replaced by the different mineral admixture by weigh [23, 24]. To measure the workability, slump, compaction factor, vee-bee shear test as per I.S 1199-1959 [25] and flow table test as per I.S. 9103-1999 [26] were carried out for each replacement level of natural sand to manufactured sand and cement by mineral admixtures. To determine the harden properties of concrete, tensile strength tests were carried out on cylindrical specimens of size 150 mm diameter and 300 mm height after 28 days curing as per I.S. 5816-1999 [27] (Figs. 1, 2, 3, 4 and 5).

Fig. 1 Slump test

Fig. 2 Compaction factor test

4 Results and discussions

4.1 Fresh concrete properties

Fresh concrete or plastic concrete is a freshly mixed material which can be moulded into any shape. The workability (Fresh concrete test) test results carried out by using slump, compaction factor, flow and vee bee degree with different percentage replacement of natural sand by manufactured sand and 20% cement replaced by different pozzolanic materials are shown in Tables 2, 3, 4 and 5. From the test results obtained, it is observed that as percentage replacement of natural sand by manufactured sand is increased there is decrease in workability properties. The reasons for reduction in workability are due the angular shape and rough surface of manufactured sand which imparts more internal friction there by reducing the flow characteristics of concrete.

4.2 Tensile strength

The tensile strength of concrete is one of the basic and important properties which greatly affect the extent and size of cracking in structures. Moreover, the concrete is very weak in tension due to its brittle nature. The tensile strength tests are carried out for different replacement of natural sand by manufactured sand and 20% cement replaced with fly ash, silica fume, GGBFS and metakaolin in concrete and are shown in Table 6. From test results obtained it is observed that the reference concrete specimen made with 0% manufactured sand and without any pozzolanic materials has exhibited less strength. It is seen that the tensile strength shows an increasing trend up to 60% replacement of natural sand by manufactured

Fig. 3 Flow table test

Fig. 4 Vee-Bee degree test

Fig. 5 Tensile strength test on cylinde

sand. After 60% replacement level, the tensile strength decreases thus, the higher tensile strength is obtained at 60% replacement of natural sand by manufactured sand and its value is 4.35 MPa. This is true for concretes produced by replacing cement by fly ash or silica fume or GGBFS or metakaolin also with tensile strength values 4.39 MPa, 4.72 MPa, 4.66 MPa, and 4.70 MPa respectively. As per Table 7, the percentage increase in the tensile strength is found to be 16.13%, 15.12%, 16.5% and 14.63% respectively. This is due to fact that 60% replacement of natural sand by manufactured sand changes internal microstructure and morphology of concrete thereby resulting in denser concrete with minimum voids. The dense particle packing and optimal size distribution is responsible for increased tensile strength. Also it is observed that the concrete produced by replacing cement by silica flume with manufactured sand yields good tensile strength as compared to concrete produced by replacing cement by fly ash or GGBFS or metakaolin thus, higher tensile strength is obtained for concrete produced by replacing cement by silica flume and by using manufactured sand. The improvement in tensile strength is mainly attributed to the excellent pozzolanic reaction of silica fume which produce additional C–S–H gel and which is responsible for filling the micro voids thereby resulting in denser concrete with improved microstructure [28].

The second better pozzolana which exhibits maximum tensile strength is metakaolin. The third better pozzolana is GGBFS and the fourth better pozzolana is fly ash. The concrete produced without pozzolana exhibits less tensile strength as compared to concrete with pozzolanas. Thus the study clearly indicates that concrete produced by replacing 20% cement by silica fume has the potential to increase the tensile strength in concrete.

Table 2 Slump (mm) values with different pozzolanic materials

Percentage replacement of natural sand by manufactured sand	No replacement of cement	Cement replaced by fly ash	Cement replaced by silica fume	Cement replaced by GGBFS	Cement replaced by metakaolin
0	100	98	98	98	99
10	95	96	95	94	96
20	94	95	94	94	95
30	90	93	92	93	94
40	85	85	92	92	92
50	85	85	88	90	89
60	84	85	82	88	84
70	80	82	80	82	82
80	80	80	78	82	82
90	75	76	76	80	78
100	75	76	74	74	72

Table 3 Compaction factor values with different pozzolanic material

Percentage replacement of natural sand by manufactured sand	No replacement of cement	Cement replaced by fly ash	Cement replaced by silica fume	Cement replaced by GGBFS	Cement replaced by metakaolin
0	0.885	0.910	0.900	0.912	0.889
10	0.862	0.864	0.892	0.889	0.885
20	0.862	0.863	0.890	0.865	0.882
30	0.860	0.860	0.888	0.862	0.880
40	0.858	0.858	0.885	0.860	0.878
50	0.858	0.857	0.884	0.860	0.875
60	0.852	0.857	0.853	0.859	0.875
70	0.852	0.853	0.852	0.855	0.871
80	0.848	0.853	0.852	0.855	0.855
90	0.845	0.852	0.850	0.850	0.850
100	0.820	0.830	0.827	0.832	0.825

Table 4 Flow (%) values with different pozzolanic materials

Percentage replacement of natural sand by manufactured sand	No replacement of cement	Cement replaced by fly ash	Cement replaced by silica fume	Cement replaced by GGBFS	Cement replaced by metakaolin
0	96	92	92	94	96
10	92	92	88	92	94
20	92	90	88	92	94
30	86	88	87	90	88
40	84	86	85	88	88
50	83	83	84	87	84
60	48	52	60	56	72
70	44	52	48	54	48
80	44	50	46	50	44
90	38	40	32	50	44
100	32	33	28	40	34

Table 5 Vee-Bee degree (second) values with different pozzolanic materials

Percentage replacement of natural sand by manufactured sand	No replacement of cement	Cement replaced by fly ash	Cement replaced by silica fume	Cement replaced by GGBFS	Cement replaced by metakaolin
0	5.0	5.0	5.0	5.0	5.0
10	6.0	6.0	5.0	5.0	5.0
20	6.0	6.0	6.0	6.0	6.0
30	7.0	7.0	6.0	6.0	6.0
40	7.0	7.0	6.0	7.0	6.0
50	7.0	7.0	7.0	7.0	7.0
60	8.0	8.0	7.0	7.0	7.0
70	8.0	8.0	8.0	8.0	7.0
80	8.0	9.0	8.0	8.0	8.0
90	9.0	9.0	9.0	9.0	8.0
100	11.0	10.0	10.0	10	11.0

Table 6 Tensile strength (MPa) results with different pozzolanic materials

Percentage replacement of natural sand by manufactured sand	No replacement of cement	Cement replaced by fly ash	Cement replaced by silica flume	Cement replaced by GGBFS	Cement replaced by metakolain
0 (Ref.)	3.73	3.78	4.10	4.00	4.10
10	3.74	3.78	4.30	4.20	4.20
20	3.95	3.98	4.42	4.30	4.40
30	3.98	3.99	4.62	4.40	4.49
40	4.10	4.14	4.69	4.60	4.69
50	4.21	4.23	4.70	4.62	4.69
60	4.35	4.39	4.72	4.66	4.70
70	3.65	4.31	4.66	4.56	4.65
80	3.53	4.22	4.59	4.44	4.56
90	3.37	4.00	4.40	4.21	4.33
100	3.35	4.05	4.33	4.12	4.20

Table 7 Percentage increase of tensile strength test results

Percentage replacement of natural sand by manufactured sand	No replacement of cement	Cement replaced by fly ash	Cement replaced by silica flume	Cement replaced by GGBFS	Cement replaced by metakolain
0 (Ref.)	–	–	–	–	–
10	+0.26	0	+4.87	+5.0	+2.43
20	+5.89	+5.29	+7.80	+7.5	+7.31
30	+6.70	+5.55	+12.68	+10.0	+9.51
40	+9.91	+9.52	+14.39	+15.0	+14.39
50	+12.86	+11.90	+14.63	+15.5	+14.39
60	+16.62	+16.13	+15.12	+16.5	+14.63
70	+2.14	+14.02	+13.65	+14.0	+13.41
80	+5.36	+11.64	+11.95	+11.0	+11.21
90	+9.65	+5.82	+7.31	+5.25	+5.60
100	+10.18	+7.14	+5.60	+3.0	+2.43

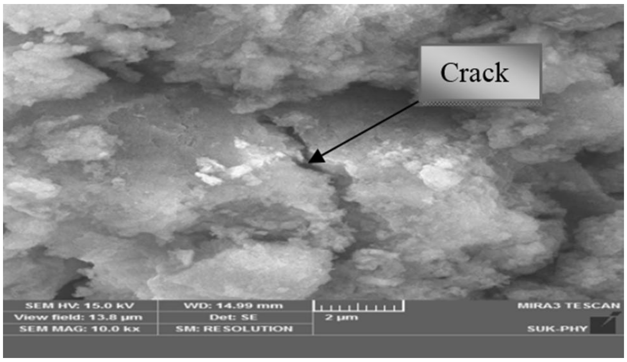

Fig. 6 SEM photograph for concrete with 0% replacement of natural sand by manufactured sand and cement replaced by silica fume

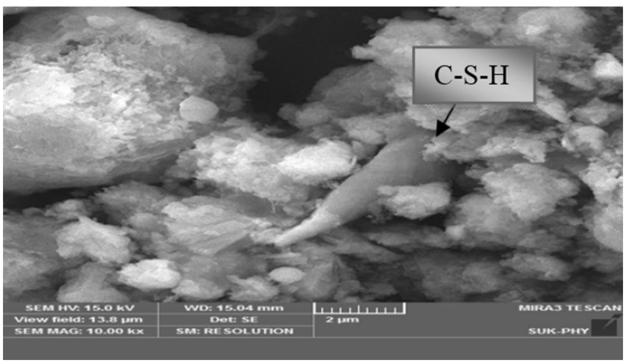

Fig. 7 SEM photograph for concrete with 20% replacement of natural sand by manufactured sand and cement replaced by silica fume

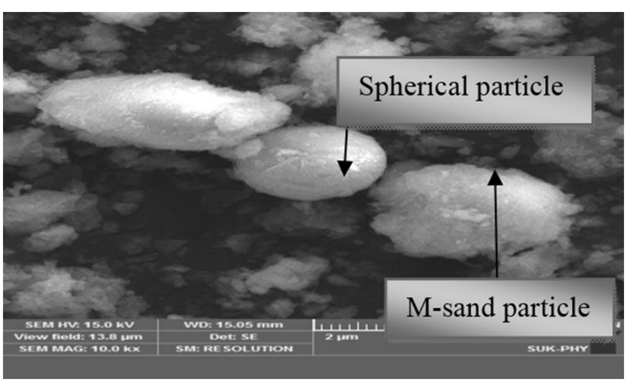

Fig. 8 SEM photograph for concrete with 40% replacement of natural sand by manufactured sand and cement replaced by silica fume

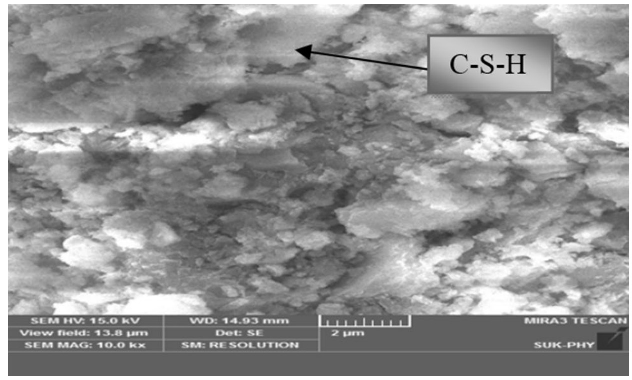

Fig. 9 SEM photograph for concrete with 60% replacement of natural sand by manufactured sand and cement replaced by silica fume

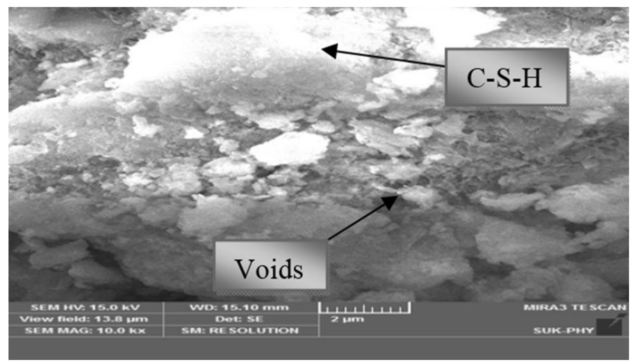

Fig. 10 SEM photograph for concrete with 80% replacement of natural sand by manufactured sand and cement replaced by silica fume

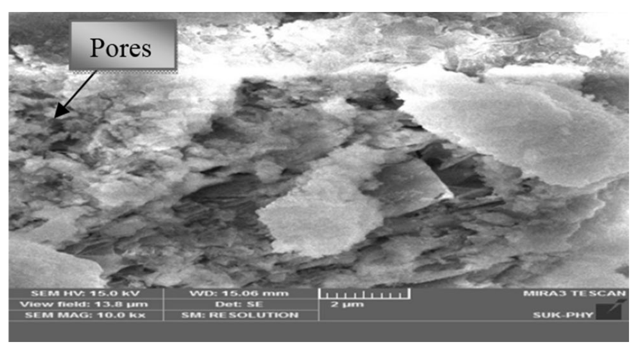

Fig. 11 SEM photograph for concrete with 100% replacement of natural sand by manufactured sand and cement replaced by silica fume

5 Scanning electrons microscope (SEM) analysis

Comparative photograph for different percentage replacement of natural sand by manufactured sand and cement replaced with silica fume are shown in Figs. 6, 7, 8, 9, 10 and 11. Figure 6 is SEM photographs of concrete produced from 0% replacement of natural sand by manufactured sand with silica fume. It shows the

C–S–H gel in bright and dark matter in courser lumps. It is also observed that matrix has less crowed and evenly packed with hydration products. Air voids and millimeter size cracks were observed. Pore diameter is of order of 1–5 µm. Significantly it increases the porosity with less packing of materials [29]. Figure 7 is SEM photographs of concrete produced from 20% replacement of natural sand by manufactured sand with silica fume. It shows the matrix has less crowed and uniformly packed with hydration products. The number of voids in the matrix has significantly reduced, diameter is of order of 1–3 µm. which ultimately reduces the porosity resulting slightly increase in tensile strength [30]. Figure 8 is SEM photographs of concrete produced from 40% replacement of natural sand by manufactured sand with silica fume. It shows the C–S–H gel is uniformly finer. Medium dark particles considered as manufactured sand particles. It is observed that matrix has moderately crowed and uniformly packed with hydration products. No cracks and voids are found [30]. Figure 9 is SEM photographs of concrete produced from 60% replacement of natural sand by manufactured sand with silica fume. It shows the matrix has extremely crowed with densely packed hydration products. No cracks and voids are found. Due to denser microstructure porosity reduces that creates better packing of materials. This enhances the strength of concrete [31]. Figure 10 is SEM photographs of concrete produced from 80% replacement of natural sand by manufactured sand with silica fume. It shows the matrix has moderately crowed with uniformly packed with hydration products. Voids are found, resulting decrease in tensile strength [31]. Figure 11 is SEM photographs of concrete produced from 100% replacement of natural sand by manufactured sand with silica fume. It shows the C–S–H in form of course lumps. It is observed that matrix has less crowed with uniformly packed hydration products. Micro cracks and micro pores can be clearly observed [31].

6 X-ray diffraction (XRD) analysis

X-ray diffraction is a powerful nondestructive technique for identify various phases present in the hardened concrete. Diffraction angle of 2θ was used. The comparative X-ray diffraction pattern are shown in Fig. 12. It is observed that the reference concrete specimen made with 60% manufactured sand and without any pozzolanic materials has exhibited more diffraction peak intensity. It is clearly observed that diffraction peak intensity is very low for 60% replacement of natural sand by manufactured sand and partly cement replaced by silica fume as compared to reference concrete [32]. Structural study indicates that the intensity of peak decreases from reference concrete to concrete made by using 60% replacement of natural sand by manufactured sand and partly replacing cement with silica fume. It was clear that the major component in the sample is silica content due to the peak of 27° (JCPDS) and all the samples are crystalline in nature [33].

7 Energy dispersive spectroscopy (EDS) analysis

Figures 13, 14, 15, 16 and 17 provides the EDS mapping. The element compositions from the EDS analysis showed that the particles where mostly composed of three elements. Calcium (Ca), Carbon (C) and Oxygen (O). The

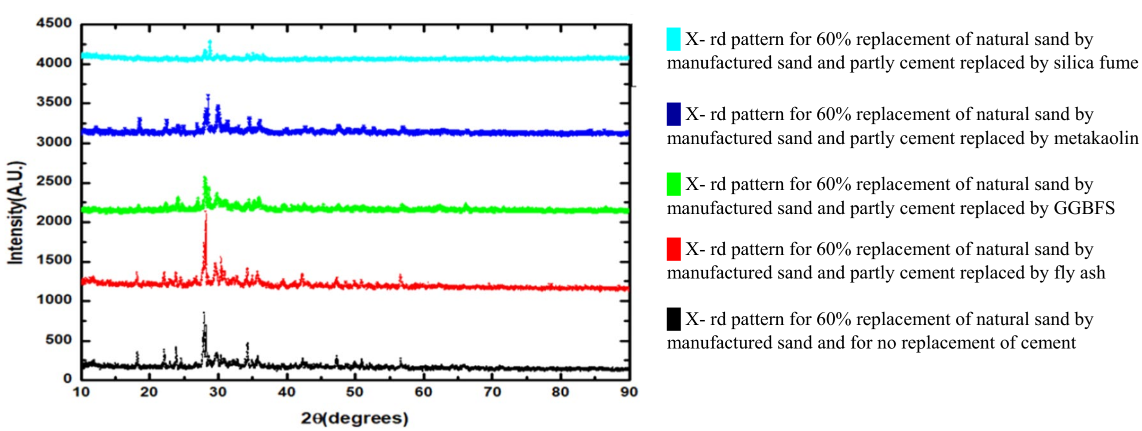

Fig. 12 Comparative X-ray diffraction pattern

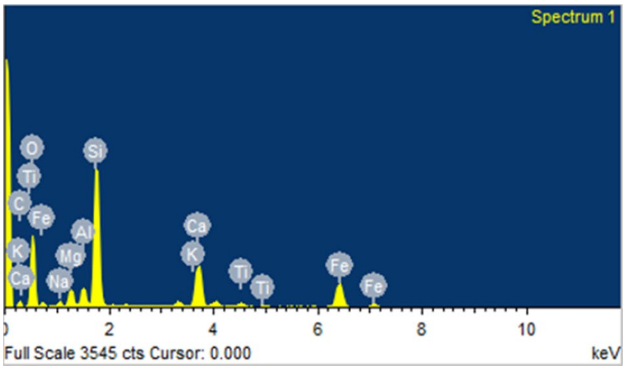

Fig. 13 EDS mapping for 60% replacement of natural sand by manufactured sand and no replacement of cement

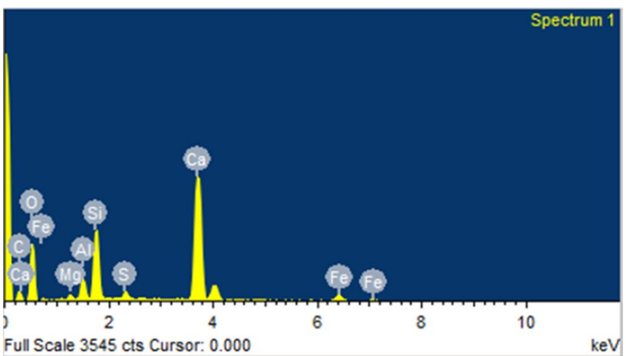

Fig. 14 EDS mapping for 60% replacement of natural sand by manufactured sand and partly cement replaced by fly ash

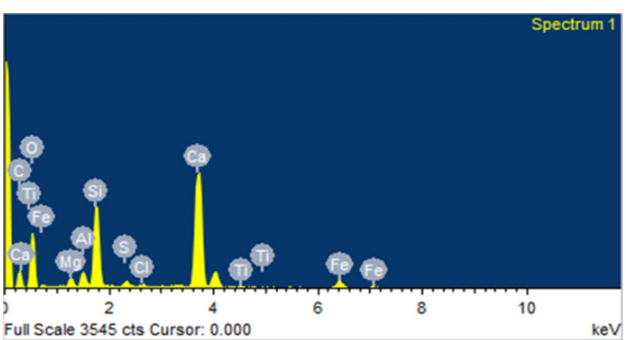

Fig. 15 EDS mapping for 60% replacement of natural sand by manufactured sand and partly cement replaced by silica fume

weight ratio among those elements closely match with $CaCO_3$ (Calcium carbonate).which clearly indicate that those particles were $CaCO_3$. Which enhance the strength of concrete [28, 34].

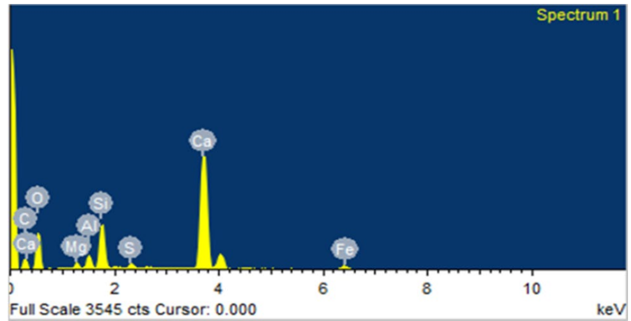

Fig. 16 EDS mapping for 60% replacement of natural sand by manufactured sand and partly cement replaced by metakaolin

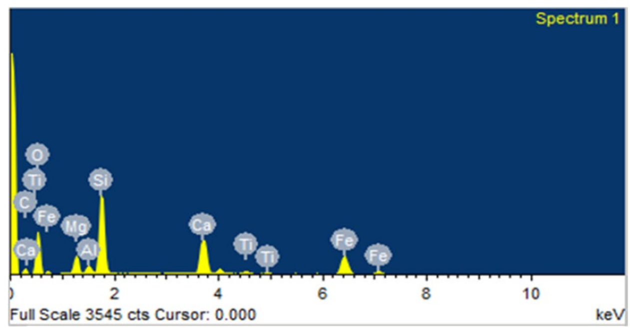

Fig. 17 EDS mapping for 60% replacement of natural sand by manufactured sand and partly cement replaced by GGBFS

8 Conclusions

- Workability of concrete is seriously affected as the percentage replacement of natural sand by manufactured sand increases.
- Higher tensile strength for concrete is obtained at 60% replacement of natural sand by manufactured sand. This is true for concrete produced by replacing cement by fly ash or silica fume or GGBFS or matakaolin. Also it may be concluded that the concrete produced by replacing cement by silica flume with manufactured sand exhibits improved compressive strength and the value being 4.72 MPa.
- The pozzolanic material (Silica fume, metakaolin, GGBFS and fly ash) used in the present work have shown that for 60% percentage replacement of natural sand by manufactured sand do improve the microstructure of concrete as compared to concrete without any pozzolanic materials.
- Major minerals present in the concrete sample are silica, calcium and oxides. Calcium reacts with silica and oxides, and produces the hydrated calcium silicates, which impart strength to the concrete.

- The possibility of substituting natural sand with manufactured sand and cement with industrial by-product such as fly ash, silica fume, metakaolin. GGBFS offers technical, economical and environmental advantages which are of great importance in the present situation of sustainability in the construction area.

Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest.

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