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UTILIZATION OF MUNICIPAL SOLID WASTE INCINERATION BOTTOM ASH IN MANUFACTURED SAND FOR SUSTAINABLE CONCRETE

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ABSTRACT
The necessity of using manufactured sand (M-sand) stems from the depletion of natural sand resources, which has led to environmental degradation and scarcity. M-sand provides a sustainable alternative with consistent quality, enhanced properties for concrete, and reduced impurities, offering better workability, bonding, and durability. It is also cost-effective due to local production, stable pricing, and reduced transportation costs. Moreover, M-sand contributes to environmental preservation by minimizing the impacts of sand mining and utilizing industrial waste, aligning with regulatory standards, and promoting sustainable construction practices. The incineration of municipal solid waste generates incineration bottom ash. This bottom ash is disposed of in landfills, leading to growing concerns about landfill shortages and environmental sustainability, which has sparked interest in exploring alternative uses for this by-product. Municipal solid waste incineration bottom ash (MSWIBA) has the potential to be used as a partial replacement for river sand. In this research work, the MSWIBA is used as a substitute for fine aggregates in the production of mortar and concrete. The M sand was prepared by removal of unwanted material, followed by grinding and sieved from a 1.18 mm sieve, which exhibits a fineness modulus of ~4.99, specific gravity of ~2.26, water absorption of ~2.67 %, and falls under Zone II. The river sand was replaced at a ratio of 20%, 50%, and 80% sand, and 100% by M sand. The efficacy of sand replacement was seen in terms of the compressive strength of mortar at 7 days. The mixed sand prepared with 20% of River sand and 80% MSWIBA is used for concrete casting. The fresh, hardened, and durability properties of concrete are evaluated at the age of 28 days.

Keywords: *River sand, Manufactured sand (M sand), Municipal solid waste incineration bottom ash (MSWIBA), Concrete*

1. INTRODUCTION
Mixtures of cement, water, aggregates (both coarse and fine), admixtures, fibers, and other additions make up concrete. River sand or natural sand is used as the fine aggregate, whereas gravel and crushed stone are used as coarse aggregates in concrete [1]. Finely split mineral and rock fragments make up the granular material known as river sand, which occurs naturally [2]. However, Sand composition can differ significantly based on the local rock sources and conditions. River sand and gravel, two of the raw resources used to make concrete, are also finding it difficult to meet the fast-rising demand in many parts of the world. As per the March 2014 publication "Sand-rarer than one thinks" by the UNEP, or the United Nations Environment Program, sand and gravel have surpassed water as the most extensively utilized natural resource on Earth. Between 47 and 59 billion tons are mined annually worldwide, with sand and gravel making up the majority (68% to 85%) of that total. An estimate of the global aggregate use for concrete in 2012 was between 25.9 billion and 29.6 billion tons annually [3]. Sand is found from massive riverbed debris removal projects as well as sandhills and coastlines [4]. Searching below the streambed modifies the form and shape of the channel, which has several negative effects, including erosion of the banks and riverbed, and changes in elevation of the channel bed's slope. Rivers and estuaries become deeper as a result and river mouths and coastal inlets increase. Activities related to in-stream sand mining deteriorate river water quality. River ecosystems are currently under threat in several places because of the environmental effects of excessive sand extraction [5]. Due to this, sand extraction from rivers has been outlawed by numerous countries worldwide. The cost of this sand is rising due to the depletion of sufficient natural sand supplies close to the site of consumption, which eventually drives up construction costs. Manufactured sand, or M sand, is a type of fine aggregate that is specifically crushed and created from a suitable source material [6]. Angular-shaped crushed fine aggregate is typically produced with the introduction of newer crushers. Owing to the artificial sand particles' greater angularity. Pilegis et al. found that M sand generated in an industry-sized crusher machine typically required a greater water-to-cement (w/c) ratio to achieve workability comparable to natural sand concrete. M sand concrete has greater compressive and flexural strengths than natural sand concrete at the same weight-to-cement ratio [7]. According to research by B Vijaya et al., adding M sand to concrete enhances its bonding properties. The angular shape of the M-sand particles, and the rough surface texture all work together to strengthen bond qualities by enhancing internal friction and improving the interlocking of the M sand particles with the rebar [8]. The use of M sand, which is created from

crushed rocks, in place of natural sand was examined by Vijay et al. in 2015. The replacement ratios were 30%, 40%, 50%, and 60% and 100% for the three distinct concrete mix proportions such as M30, M40, and M50 [9]. The concrete's strength and workability when M sand is used in place of natural sand in percentages of 0%, 20%, 40%, 60% and 100% were examined by Reddy M et al. in 2015 [10]. Remember that rock and stone, which are also natural resources like river sand, are broken to create manufactured sand and crushed sand [11]. As a result, increasing the usage of manufactured and crushed sand may also result in the over-mining of the stones and pebbles. In the long run, this will be the beginning of a new class of environmental issues. Thus, it is time to approach this problem differently. Numerous industrial waste products have been effectively employed in place of natural fine aggregate, both totally and partially. Siddique Rafat et al. provided an overview of the use of different industrial waste products and by-products, for the fresh, mechanical and durability qualities of concrete, consider using wood ash, waste foundry sand, cement kiln, coal bottom ash, and dust as partial substitutes for natural sand [12]. The use of different industrial waste products and by-products, such as waste sand from foundries, ferrochrome slag from blast furnaces, copper, steel, and other slags, palm oil clinker, coal bottom ash, etc, as a substitute for fine aggregate was also covered in a review article published by Dash et al. [13]. Hun Woo et al. studied the substitution of IBA for river sand at varying ratios of 0%, 5%, 10%, 15%, and 20%. Compressive strength rises for all cases. In comparison to IBA10, IBA20 had a comparatively lower value, while IBA10 displayed the greatest value. Both IBA10 and IBA20 demonstrated the filler effect effectively [14]. Amardeep et al. examined the viability of adding various particle sizes, the fine fraction (0.15–0.3 mm), medium fraction (0.3–0.6 mm), and coarse fraction (0.6–4.75 mm) of municipal solid waste bottom ash and recycled fine aggregate to sustainable cement mortars with replacement ratio of 10%, 20%, and 30% respectively [15,16].

The rapid urbanization and industrialization experienced globally have significantly increased the production of municipal solid waste (MSW), resulting in the need for more effective waste management strategies [17]. MSW management is critical due to the environmental hazards posed by landfill accumulation, such as soil and water contamination, greenhouse gas emissions and the extensive land areas required for disposal [18]. Incineration has emerged as an effective solution to mitigate the adverse effects of MSW, reducing the volume of waste by up to 90% through combustion [19]. However, the process generates by-products, particularly incineration bottom ash, which accounts for approximately 80% of the total ash produced during the incineration process [20]. Traditionally, IBA is disposed of in landfills, but growing concerns about landfill shortages and environmental sustainability have sparked interest in exploring alternative uses for this by-product [21]. Municipal solid waste incineration bottom ash has been identified as a potential substitute for natural aggregates in construction, particularly in concrete production. The material's physical and chemical properties, which include a mixture of minerals, glass, ceramics, metals, and unburnt organic matter, make it like traditional natural aggregates [14, 15, 16, 22]. The depletion of natural sand resources, driven by the demand for construction materials, has also contributed to the growing interest in using alternative materials like MSWIBA. River sand, traditionally used in concrete production, is increasingly becoming scarce due to over-extraction, leading to environmental consequences such as riverbank erosion and habitat destruction. The substitution of MSWIBA for natural sand in concrete offers a dual benefit of reducing the environmental impact of sand mining and diverting waste from landfills, aligning with the goals of sustainable construction and waste management.

This research aims to contribute to the growing body of knowledge by evaluating the feasibility of using MSWIBA as a partial replacement for fine aggregates in concrete. The study investigates the fresh, hardened and durability properties of concrete mixtures with varying proportions of MSWIBA, providing insights into the potential for large-scale adoption of this sustainable construction material. By exploring the optimal replacement ratios and pre-treatment methods, this research seeks to identify the maximum utilization of MSWIBA in concrete while minimizing its environmental impact.

2. EXPERIMENTAL WORK

Raw Materials

In this study, Ordinary Portland Cement was procured from M/s UltraTech Cement and conformed to the specifications of IS 8112-1989. The chemical composition of cement was SiO2~ 21.98%, Al2O3~ 5.16%, CaO~ 63.25%, MgO~ 1.8%. River sand was procured from the local sources of Roorkee. The sand falls in Zone II. Municipal solid waste incinerated bottom ash (MSWIBA) was procured from Ghazipur, New Delhi. The specific gravity, Blaine's surface area, and pH value of bottom ash were 3.32, 211.2 m^2/kg, and 11.2 respectively. The properties of river sand and M sand as per IS 383 are given in the table. The gradation curve of river sand and M sand is shown in fig. 1.

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Test methods

The distribution of fine aggregate particles, or gradation, is determined as per IS: 383 (1970), which plays a crucial factor that influences the characteristics and functionality of building materials such as asphalt and concrete. Gradation influences the workability, strength, and durability of the finished product by determining how well the aggregate packs together. When aggregates are graded properly, they function at their best in their intended use. The physical properties of fine aggregates like specific gravity, water absorption, bulk density and void ratio are determined as per the specifications given in the IS: 2386-3 (1963). As per IS-2386, the specific gravity is determined with a pycnometer by taking the saturated surface dry sand. Bulk density is determined by the density pot in both loose and rodded conditions. Void ratio is directly computed from the specific gravity and bulk density as per IS-2386. Similarly, the Water absorption is determined by taking the saturated water sample in oven for 24 hours at a temperature of 105°C. The compressive strength of mortar cube (50 mm x 50 mm x 50 mm) and concrete cube (150 mm x 150 mm x 150 mm) was tested using cube specimens in accordance with Indian Standard Specifications IS: 516-1959. For the compressive strength test, a 2000 kN capacity Compression Testing Machine (CTM) with a loading rate of 140 kg/cm2/min was used to evaluate the mortar and concrete strength at the ages of 7 and 28 days. A splitting tensile strength test was conducted using standard cylindrical specimens of 150 mm in diameter and 300 mm in height at a 28-day age, in accordance with the specifications provided in BIS 5816:1999. A 2000 kN capacity compression testing machine (CTM) was employed, and a consistent loading rate ranging from 1.2 N/mm2/min to 2.4 N/mm2/min was applied. In accordance with IS:516-1959, the concrete specimens (100 x 100 x 500 mm) were tested for their modulus of rupture (flexural strength) using a 400 kN Universal testing machine. The rapid chloride-ion permeability test was assessed in accordance with ASTM C 1202. A rapid test for chloride-ion permeability was conducted on standard cylindrical specimens measuring 50 mm in height and 100 mm in diameter after 28 days. As to guarantee adequate curing, concrete specimens were demoulded after 24 hours of casting and followed by water curing for 7 and 28 days. For each test, a minimum of 3 samples were tested, and the average value was recorded.

Casting of concrete

M20 grade concrete with cement: sand: aggregate ratio of 1:1.5:3 was casted as per specifications given in IS:456-2021. A planetary mixer of capacity 60L was used for the casting of concrete. All the dry ingredients were first mixed for around 2-3 minutes until the all the materials were properly mixed. Half of the water was added to wet the mix and then remaining half was further added and the whole mix was homogenously mixed for around 5-8 minutes. First batch of control mix was prepared of around 120 kg, and the second batch included the mix made with 80% river sand replacement of also 120 kg. After mixing of the concrete, fresh density and slump was computed. The concrete mix was filled into 6 cubes of size 150x150x150 mm, 3 cubes of size 100 x100 x 100 mm for compressive strength, 3 cylinders of size (150x300 mm) for split tensile strength, 3 prisms of size (100x100x500 mm) for Flexural strength, 2 discs of size (100x50 mm) for Rapid chloride penetration test. All the moulds were vibrated for around 1-2 minutes so that voids can be eliminated. The demoulding was done after 24 hrs. of casting and put in water tank for curing. The Compressive strength was tested at 7 days with cube (100x100x100 mm) and at 28 days with cube (150x150x150 mm). The Split tensile strength, Flexural strength and Rapid chloride penetration test was tested at 28 days and observations were noted.

3. RESULTS AND DISCUSSION

3.1 Properties of River sand and M sand

The physical properties of river sand and M sand are determined as per IS: 2386-3 (1970) and are shown in Table 1. It can be observed that the specific gravity of M sand is slightly lesser than the river sand because of the lighter raw materials. The M sand have finer sizes and large specific surface areas resulting in higher water absorption, higher Fineness modulus, lower Bulk density, and higher void ratio.

Table1: Properties of River sand and M sand

Properties	River sand	M sand
Specific gravity	2.62	2.26
Water absorption (%)	1	2.67
Fineness modulus	2.39	4.99
Zone	II	II
Loose bulk density (g/cm^3)	1.46	0.94
Rodded Bulk density (g/cm^3)	1.6	1.13
Void ratio	0.389	0.4

3.2 Gradation of River sand and M sand

The gradation curve of river sand and M sand is done as per the specifications of IS:383 (1970). From Fig. 1 it can be observed that the gradation curve of River and M sand follows the maximum and minimum limits of IS code. The fineness modulus of River sand and M sand are 2.39 and 4.99. Hence both sands fall under Zone II.

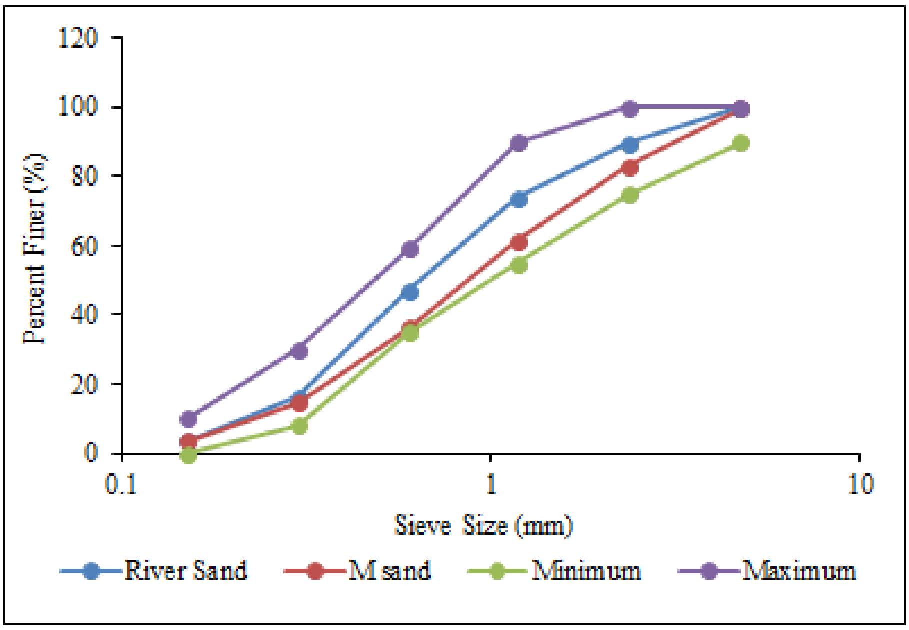

Fig. 1 Gradation of River sand and M sand

3.2 Optimization of fineness of MSWIBA

To utilize MSWIBA in concrete, firstly the effect of its particle size was assessed based on mortar strength. MSWIBA sieved from different mesh sizes like 4.75 mm, 2.36 mm, 1.18 mm and 0.6 mm were taken and mortar samples were prepared. The w/c ratio for all the case was fixed as 0.45. The mortar cubes were cast, demoulded, and cured in water and its compressive strength was evaluated after 7 days. It can be observed from fig. 2 that the maximum strength was achieved in case of mortar containing MSWIBA sieved from 1.18 mm. The compressive strength of mortar cubes containing MSWIBA sieved from 4.75 mm and 2.36 mm was inferior may be due to the improper packing of courser particles size. The strength of 0.6 mm was less than 1.18 because its particles were finer in size so since the w/c ratio was same for all the mixes which may have led to the non-wetting of some of the finer particles of 0.6 mm size. Therefore, the particles sieved from 1.18 mm was taken for further analysis of the research work.

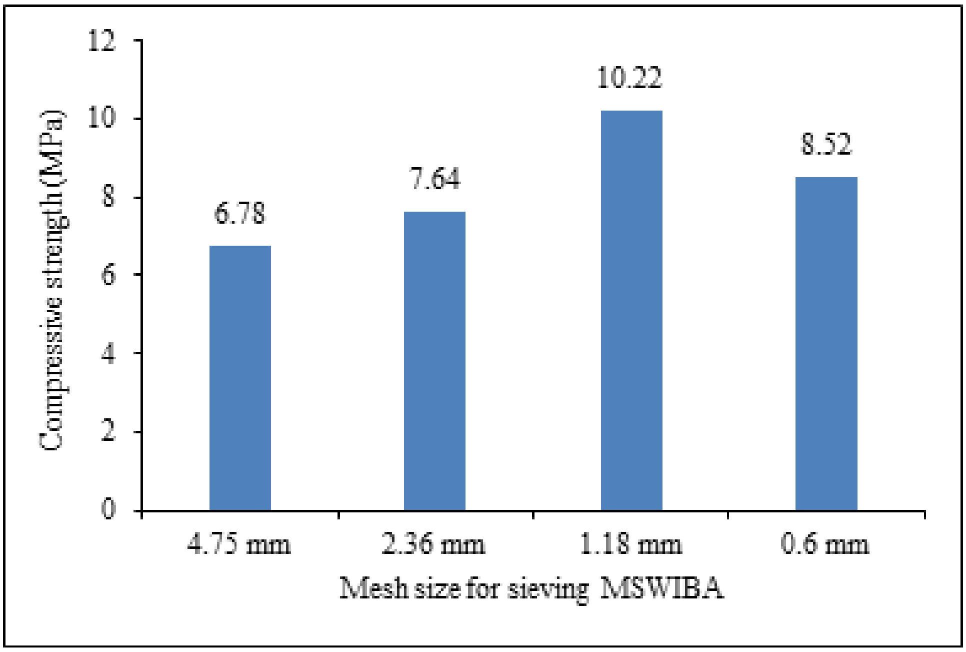

Fig. 2 Comparative analysis of compressive strength with mesh size for sieving MSWIBA

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3.3 Gradation of Mixed Sand Prepared

The gradation of Mixed sand prepared is done as per as per the specifications in IS:383 (1970). The Mix. sand is prepared by mixing of 20% M sand and 80 % River sand. From fig. 3 it can be observed that Mix. sand prepared falls under Zone II and having fineness modulus is 3.018.

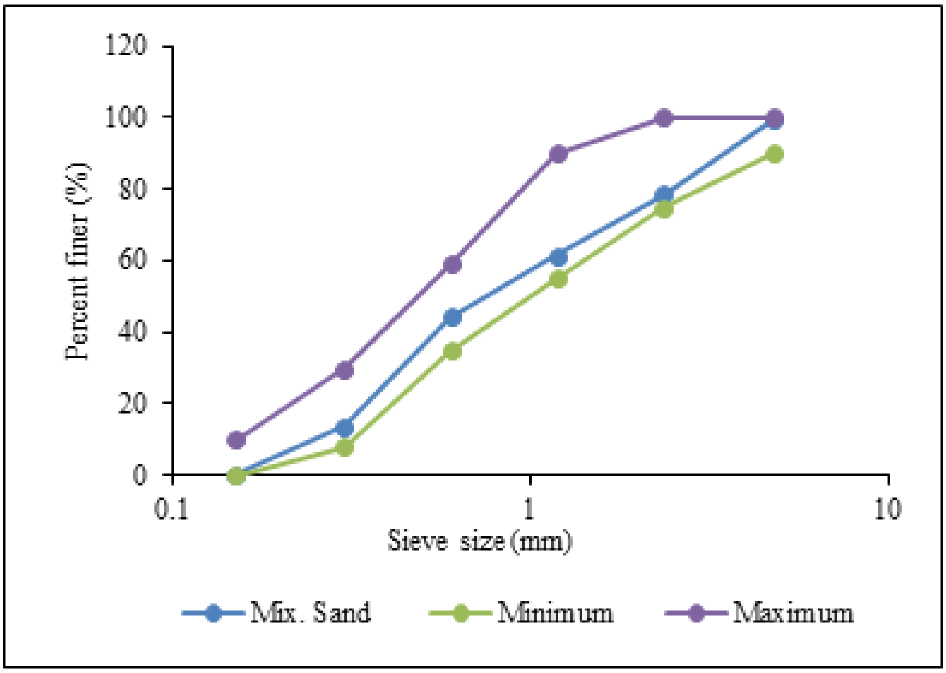

Fig. 3 Graph of gradation of Mix. sand prepared (80% M sand + 20% River Sand)

3.4 Optimization of sand replacement

The replacement of river sand with M sand was optimized by the compressive strength test. Mortar cubes were cast at replacement ratio of 0%, 20%, 50%, 80%, 100% with the M sand. From Fig. 4 it can be observed that the compressive strength of mortar cubes increases with the replacement of river sand with M sand. The compressive strength increases 98.35%, 45.6%, 33.33%, 24.28% at replacement ratio of 20%, 50%, 80%, 100% respectively. So, the river sand can be replaced with M sand up to 80% as it gives higher compressive strength. For further studies, 80% replacement of River sand with M sand was opted to utilize the Maximum MSWIBA.

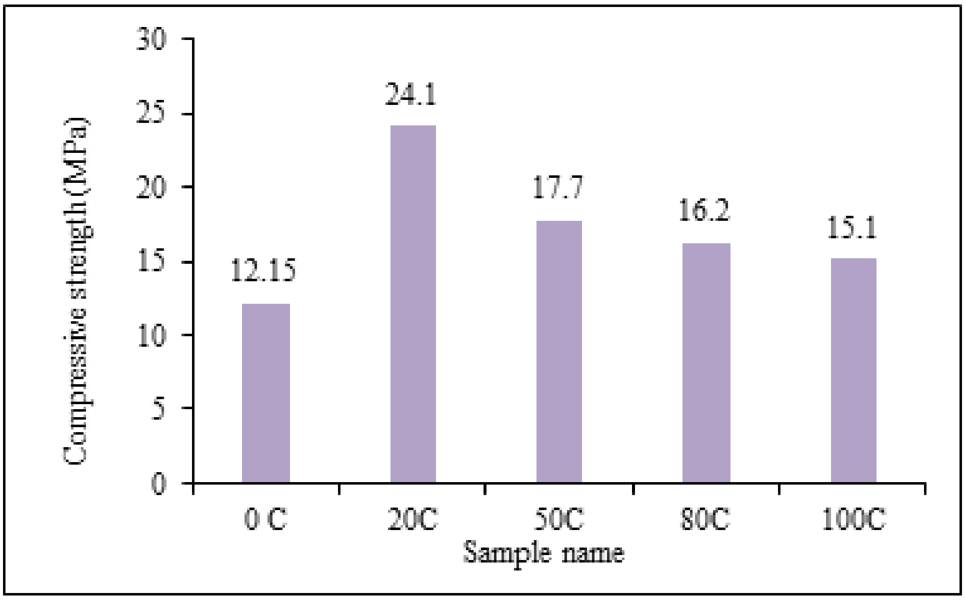

Fig. 4 Comparative analysis of compressive strength with sieved MSWIBA

3.6 Mechanical Properties of concrete

- **Fresh properties**

The slump value of M20 concrete specimens made from the river and M sand are 62 mm and 50 mm, respectively are shown in Table 2. The control concrete, which having river sand, has a consistent particle size distribution and surface texture, leading to better workability and medium slump. The M sand concrete mix, which replaced the river sand with 80% MSWIBA, resulted in reduced slump value because the ash has an irregular shape, rougher texture, and higher porosity compared to natural sand, leading to increased water demand and reduced workability, thus lowering the slump to 50 mm. The fresh density of M20 concrete specimens made from the river and M sand is calculated during casting stage found to be 2432 and 2355 kg/m^3, respectively are shown in Table 2. The control concrete, has a relatively higher density due to its compact and uniform mineral particles. In contrast, M sand concrete has the lowest density because the bottom ash is generally less dense, containing lighter and more porous particles which reducing the overall density. There is change in air content of M20 concrete specimens with river and M sand as shown in Table 2. The control concrete, has a lower air content of 2.9% because it is more homogeneous and has fewer porous particles. In contrast, M sand concrete has the highest air content of 3.3%. The bottom ash contains more irregular and porous particles, further increasing the air content.

The change in flow of mortar between the river and M sand is observed as shown in Table 2. The control, has a flow value of 110 mm, which is likely due to its consistent particle size and smooth surface texture. In contrast, M sand concrete has the lowest flow of 95 mm which is likely because the MSW bottom ash contain irregularly shaped particles and potentially higher surface roughness, leading to more friction and less flowability compared to the control.

- **Hardened properties**

The dry density observed in the M20 concrete specimens using river and M sand is 2391 and 2305 kg/m^{3,} respectively, and is shown in Table 2. The control concrete has a relatively higher density due to its compact and uniform mineral particles. The M sand concrete has voids and lower-density particles within the mix. The water absorption of M20 concrete specimens with river and M sand is 1.4 and 1.8%, respectively, are shown in Table 2. The M sand concrete has slightly higher water absorption than the control concrete, possibly due to the denser microstructure, which reduces porosity. However, it still absorbs more water than the river sand, likely because the MSW bottom ash may still retain some inherent porosity or irregularities compared to the well-graded natural sand.

From fig. 5, the compressive strength of the M20 concrete specimens with river and M sand at 7 days are 26.4 and 13.6 MPa and at 28 days are 33.36 and 17.53 MPa, respectively. At 7 days, there is a decrease in compressive strength of M sand concrete when compared to Control concrete 48.48%. At 28 days, the decrease in Compressive strength compared to Control concrete of M sand concrete by 47.45%. It was observed compressive strength decreased at 7 and 28 days, the reason attributed to the 80% replacement of river sand with the MSWIBA. As the bottom ash contains alkalis, so this may be the reason for the alkali silica reaction between ash and the aggregates resulting in decrement of strength. So, there is a decrease in compressive strength of M sand concrete due to alkali silica reaction.

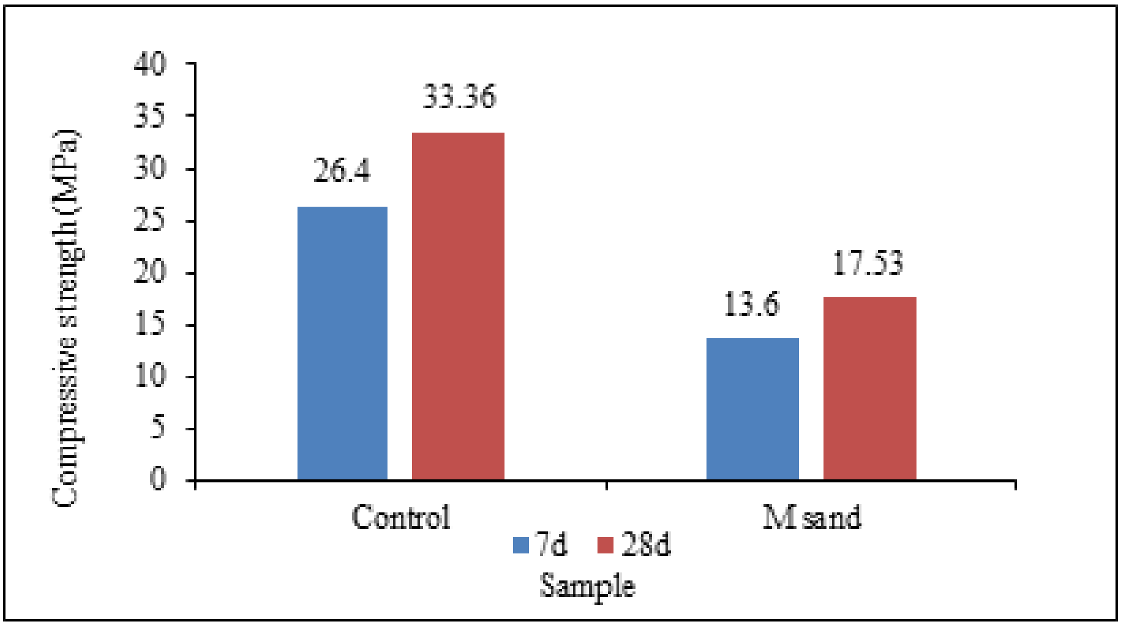

Fig. 5 Comparative compressive strength analysis of concrete

From Fig. 6, the flexural strength of the M20 concrete specimens with river and M sand is 4.055 and 3.715 MPa, respectively. The flexural strength of M sand concrete is decreased by 8.83% compared to the control concrete. The decrease in flexural strength of M sand concrete is due to alkali-silica reaction (ASR), which degrades the concrete's strength.

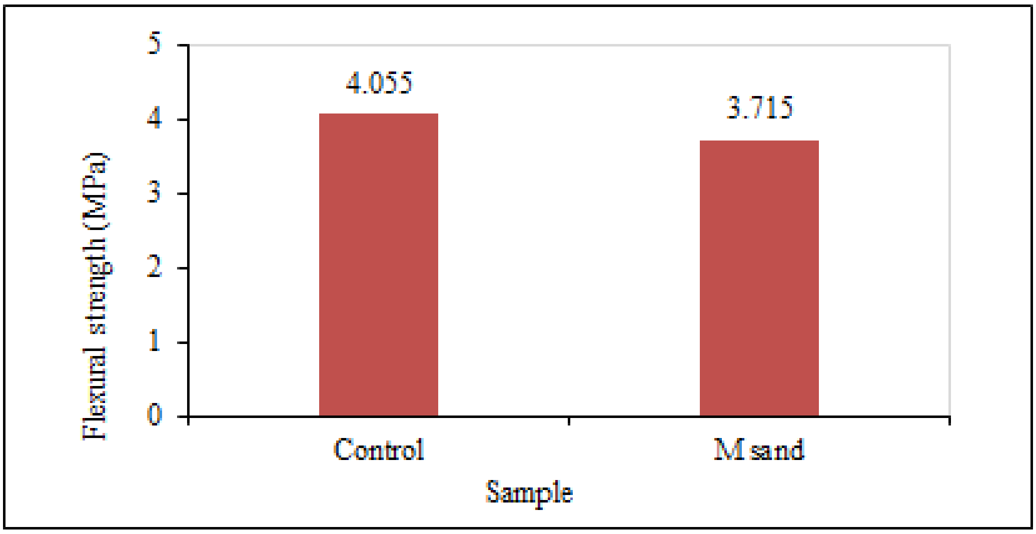

Fig. 6 Comparative flexural strength analysis of concrete

From Fig. 7, the splitting tensile strength of the M20 concrete specimens with river and M sand is 2.266 and 1.53 MPa, respectively. The splitting tensile strength is decreased in M sand concrete by 32.48% compared to the control concrete. The decrease in split tensile strength of M sand is due to alkali-silica reaction (ASR), which degrades the concrete's strength.

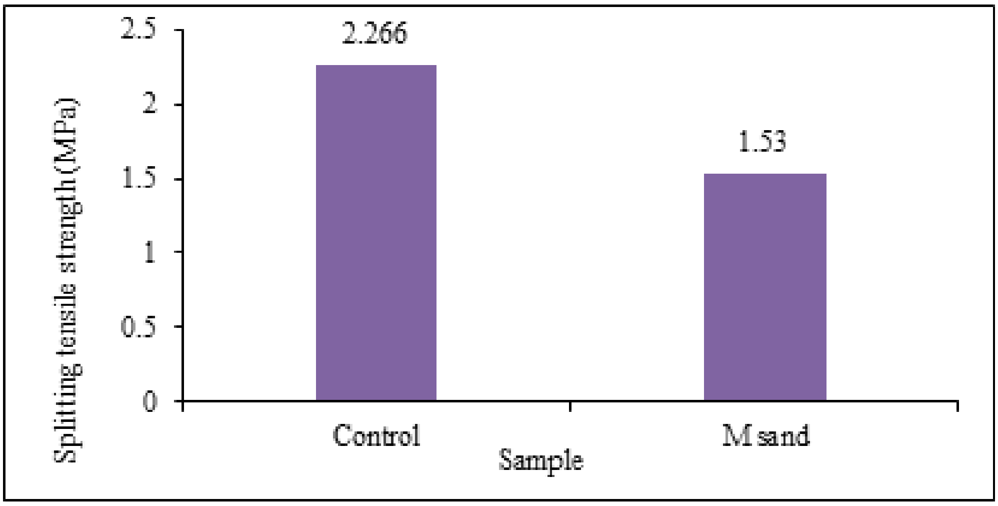

Fig. 7 Comparative Splitting tensile strength analysis of concrete

Table 2: Fresh, Hardened properties of concrete

Sr. No	Properties of concrete	Control	M sand
	Fresh Properties		
1.	1. Slump (mm)	62	45
2.	2. Fresh density (kg/m^3)	2432	2355
3.	3. Air content %	2.9	3.1
4.	4. Flow (mm)	110	95
	Hardened Properties		
1.	Dry density (kg/m^3)	2391	2305
2.	Water Absorption (%)	1.4	1.8
3.	Compressive strength 7 days (N/mm^2)	26.4	13.6
4.	Compressive strength 28 days (N/mm^2)	33.36	17.53
5.	Flexural strength (N/mm^2)	4.055	3.715
6.	Split tensile strength (N/mm^2)	2.266	1.53

- **Durability test**

The charge passes in the Rapid chloride penetration test (RCPT) of M20 concrete specimens with river and M sand are 2757.06 and 3598.47 Coulomb, respectively, as shown in Table 3. The control concrete shows an RCPT value of 2757.06 Coulombs, indicating moderate permeability as per the ASTM classification. In contrast, the M sand concrete shows a higher RCPT value of 3598.47 Coulombs, indicating increased permeability. This higher value suggests that the M sand concrete may have a less refined pore structure, allowing more chloride ions to penetrate, which could potentially lead to reduced durability in environments where chloride exposure is a concern.

Table 3: Data of current, temperature and charges recorded during RCPT

Time (Min)	Current (mA)		Temperature (°C)		Charge passed (Coulomb)	
	Control	M sand	Control	M sand	Control	M sand
0	114	140.1	30.8	31.6	**2757.06 Moderate**	**3598.47 Moderate**
30	115.2	141.5	31.2	32.9		
60	116.9	142.5	33.8	35		
90	118.3	145.3	35.5	37		
120	121.3	151	37.3	39.3		
150	123	156.3	38.6	40.8		
180	124.1	160	39.5	42		
210	125.1	164.6	40.4	43.5		
240	125.7	167.7	41.3	44.5		
270	126	171.1	41.8	45.6		
300	126.1	173.7	42.4	46.3		
330	126.4	177.1	43.1	47.3		
360	126.6	178.2	43.5	47.9		

CONCLUSION

The river sand and M sand (prepared by sieving MSWIBA from a 1.18 mm sieve) fall in Zone II as per Indian Standard 383. MSWIBA passing from a 1.18 mm sieve exhibited compressive strength of 10.22 MPa, which is the highest among the Bottom ash passing from 4.75 mm, 2.36 mm, and 0.6mm in concrete mortar. Thus, 1.18 mm sieved bottom ash is optimized. The optimization of sand replacement with M sand is done on the basis of the compressive strength of mortar cubes. The compressive strength of mortar cubes having replacement of river sand with M sand is found to be increased at 20%, 50%, 80%, and 100% when compared to the control. Among these optimizations, the 80% replacement is opted for concrete casting as it gives compressive strength increased to 33% along with maximum utilization of MSWIBA. The experimental results revealed that the compressive strength, split tensile strength, and flexural strength of M20 concrete having 80% replacement of river sand with M sand are decreased by 12%, 32.48%, and 8.83% when compared to control concrete due to alkali silica reaction. The RCPT value of M20 concrete being controlled and M sand concrete are 2757.06 and 3598.47 Coulombs, respectively, indicating moderate permeability of ASTM. Hence, this research concluded with a remark of the maximum percentage of river sand that can be replaced with M sand, which did not produce satisfactory results due to alkali silica reaction in later age strength.

DECLARATIONS

Availability of data and materials

All data generated or analyzed during this study are included in this published article. No additional data or materials are available.

Competing interests

The authors declare that they have no competing interests.

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Authors' contributions

Anish Kushwah conducted the research, performed the data analysis, and wrote the manuscript. Devesh Jaysawal and Humaira Athar provided supervision, guidance, and critical revisions to the manuscript. All authors read and approved the final manuscript.

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