FROM WASTE TO INFRASTRUCTURE: CONSTRUCTION POTENTIAL OF MUNICIPAL SOLID WASTE BY-PRODUCTS

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ABSTRACT

The rapid urbanization and population growth in modern cities have led to a substantial increase in municipal solid waste (MSW) generation, posing severe environmental and management challenges. This study explores the potential of recycling and reusing MSW by-products in the construction industry as an effective strategy for sustainable development. By analyzing different waste components such as plastics, glass, paper, metals, and organic matter, the research identifies viable methods for converting these materials into construction inputs like bricks, concrete aggregates, road base materials, and insulation panels. Laboratory testing and literature data are used to assess the mechanical, thermal, and durability properties of MSW-derived construction materials. The findings indicate that several MSW fractions can meet industry standards when properly processed, offering both economic and ecological benefits. This study advocates for integrating waste management with construction innovation to support the circular economy and reduce the environmental burden of landfilling.

1. INTRODUCTION

1.1 General

Municipal solid waste (MSW) management is an escalating concern in the face of global urbanization, industrialization, and changing consumption patterns. With cities generating thousands of tons of waste daily, conventional disposal methods such as landfilling and incineration are proving unsustainable due to their adverse environmental impacts, including greenhouse gas emissions, groundwater contamination, and land use constraints. In response to these challenges, the reuse and recycling of MSW have gained significant attention, especially within sectors capable of absorbing large volumes of recovered materials—most notably, the construction industry.

The construction sector, traditionally known for its high resource consumption and waste generation, is increasingly embracing sustainable practices. Incorporating recycled MSW materials into construction applications not only reduces environmental pressure but also offsets the demand for virgin materials. Materials such as shredded plastics, crushed glass, fly ash from organic waste incineration, and metal scraps are now being repurposed into functional construction components including bricks, tiles, road base layers, and concrete substitutes.

This study investigates the feasibility and benefits of utilizing MSW by-products in construction, focusing on material recovery, processing techniques, performance characteristics, and environmental implications. The research emphasizes how integrating waste valorization into construction can create a symbiotic relationship between two major urban systems—waste management and infrastructure development—thus contributing to a circular and more sustainable economy.

2. LITERATURE REVIEW

2.1 General

Municipal solid waste (MSW) generally refers to domestic and commercial waste generated within the jurisdiction of a municipal authority. In most cases, MSW mainly consists of organic material, waste paper, waste glass, plastic waste, tin cans, textiles, etc. With the world hurtling toward the urban future, the growth rate of MSW has exceeded the speed of urbanization (Sun et al., 2018). It has been reported that the global MSW per annum is expected to reach 2.2 billion by 2025, which is tripled of 0.68 billion in 2002 (Hoornweg and Bhada-Tata, 2012). Fig: 2.1 presents the annual MSW generation from the selected counties (Waste Atlas, 2019). Consequently, researchers have attempted to employ this waste for the preparation of geopolymer composites. Surprisingly, they have encountered exciting and impressive discoveries in this regard. Therefore, this section deals with the emerging research studies on recycling MSW into geopolymer composites, including municipal solid waste incinerator ash, waste paper, rubber waste, plastic waste, along with some others.

Currently, incineration is commonly used practice against the context of substantial MSW. Incineration can reduce waste volume and mass by up to 90 % and 70 %, respectively (Silva et al., 2019b). Additionally, incineration allows for producing energy from waste. While after the incineration process, two types of ashes are generated, namely municipal solid waste incineration bottom ash (MIBA) and municipal solid waste incineration fly ash (MIFA). MIBA is the residue with large particles, which is found at the bed of the incinerator, whereas MIFA corresponds to the very fine particles collected by the air pollution control system (Sarmiento et al., 2019). As different characteristics of MIBA and MIFA, their utilization in geopolymer composites is discussed below separately.

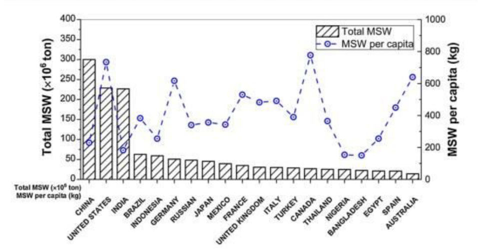

Fig. 1: Annual MSW generation from selected countries (Waste Atlas, 2019).

MIBA accounts for about 80 % of the waste combustion residues and contains much less toxic organic substances in comparison with MIFA. Thus, there exists a great potential for the utilization of MIBA rather than sending it to a landfill. Although there have been considerable efforts to valorize this waste through using it as raw material for cement production or as filler for road construction, several significant drawbacks limit the wide applications of MIBA, especially the leach of heavy metals (Siddique, 2010a).

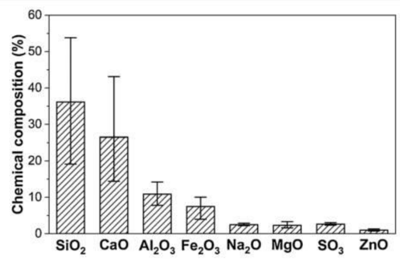

Fig: 2: (a). Chemical composition and mineralogy of MIBA: Chemical composition

of MIBA from the selected studies. Data from Chen et al. (2016); Gao et al.

(2017); Huang et al. (2018b), a; Xuan et al. (2019); Zhu et al. (2018).

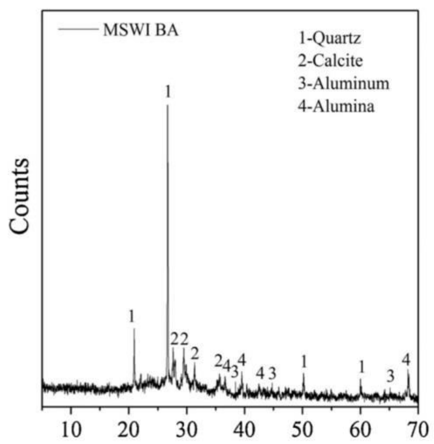

Fig. 3: (b). Chemical composition and mineralogy of MIBA: XRD

pattern of MIFA (1, CaClOH; 2, NaCl; 3, KCl; 4, SiO2; 5, CaCO3) (Li et al., 2019).

The chemical composition of the MIBA from the select studies is presented in Fig: 2 , including the average value as well as the minimum and maximum values. Also, the mineralogy of MIBA is provided in Fig: 3. Obviously, MIBA can potentially be utilized as a geopolymer precursor, due to the presence of both amorphous fraction, and high content silica and aluminum oxide. Initially, MIBA was used as a partial replacement for the precursors during the synthesis of geopolymer composites (Lancellotti et al., 2013). Lancellotti et al. (2013) demonstrated that MIBA was suitable source material for producing metakaolin blended geopolymers, with the contents up to 70 % of the precursor. The follow-up studies then examined the feasibility of using MIBA as the only geopolymer precursor (Chen et al., 2016; Lancellotti et al., 2015; Zhu et al., 2019a). For instance, through microstructure analysis and composition characterization, Chen et al. (2016) have identified the successful geopolymerization of MIBA, and the formation of new crystal phase consisting of silica, aluminum, and sodium, as shown in Fig. 3. Similar results have also been observed in the studies by Lancellotti et al. (2015) and Zhu et al. (2019a).

On the other hand, several studies have been conducted to use pretreatments such as alkaline treatment, vitrification, and wet grinding to eliminate the effect of foaming and expansion by metallic aluminate presented in MIBA (Zhu et al., 2019b). In the series of studies by Huang et al. (2019a), the alkaline treatment was employed. Specifically, MIBA was mixed with sodium hydroxide solution to form slurry and to age this slurry for 4 h, prior to preparing MIBA-based geopolymer composites. Meanwhile, several additives were incorporated during the geopolymer composite preparation for further improving the performance (Huang et al., 2018b; Huang et al., 2019a, b). The test results showed that the resulted geopolymer composites possessed satisfactory compressive strength and durability due to the high degree of geopolymerization and dense microstructure (Huang et al., 2018b; Huang et al., 2019b).

3. OBJECTIVE OF THE STUDY

The objectives of the work are stated below:

i) To develop mix design methodology for mix 25 MPa

ii) To study the effect of adding different percentages (0% - 20%) of MSW ash by the weight of cement in the preparation of concrete mix.

iii) To determine the workability of freshly prepared concrete by Slump test.

iv) To determine the compressive strength of cubes at 7, 14, 28 days.

4. EXPERIMENTAL WORK

4.1 Mix Design of Conventional Concrete (M25)

Table. 1: Design proportions of materials for M25 grade concrete.

Item name	**As per mixed Design (kg/m^3)**
Cement	438.13
Fine aggregates	645.67
Coarse aggregates	1074.06
water	197.16

4.1.1 Mixed design proportions for MSWA Concrete

- In this research work 15 Standard cubic specimens of size 150mm (nine sample for each percentage of MSWA) were casted for the compressive strength of concrete and it was kept under curing for 7, 14 days & 28 days of age. Total cubes for compressive strength testing was 45 (9 cubes * 5 proportions).
- Mass of ingredients required will be calculated for 9 no's cubes assuming 10% wastage
- Volume of the Cube = 9*1.10*(0.15)^3 =0.0334125 m^3

Table. 2: Material Proportions Cubes.

Materials	0%	5%	10%	15%	20%
Cement (Kgs)	14.64	13.908	13.176	12.444	11.712
MSWA (gms)	0	0.732	1.464	2.196	2.928
water (lit)	6.587	6.587	6.587	6.587	6.587
fine aggregate (Kgs)	21.574	21.574	21.574	21.574	21.574
Coarse aggregate (Kgs)	35.88	35.88	35.88	35.88	35.88

4.1.2 Sample Production

The cement, fine and coarse aggregates were weighted according to mix proportion of M_{25}. All are mixed in a bay until mixed properly and water was added at a ratio of 0.45. The water was added gradually and mixed until homogeneity is achieved. Any lumping or balling found at any stage was taken out, loosened and again added to the mix.

For the second series of the mixture, the MSWA was added at 5%, 10%, 15% and 20% by weight of Cement. Immediately after mixing, slump test was carried out for all the concrete series mixture. A standard 150×150×150mm cube specimen were casted.

The samples were then stripped after 24hours of casting and are then be ponded in a water curing. As casted, a total of (45) 150×150×150mm cubes specimens were produced.

Fig. 4: Cubes with MSWA.

4.1.3 Curing

The method of curing adopted was the ponding method of curing and produced samples were cured cubes for 7, 14, 28 days.

Fig. 5: Water curing of samples.

4.2 Test for Fresh Properties of Concrete (Workability Test)

4.2.1 Slump Test

which can be employed either in laboratory or at site of work. It is not a suitable method for very wet or very dry concrete. It does not measure all factors contributing to workability, nor is it always representative of the placability of the concrete. It is not a suitable method for very wet or very dry concrete. It does not measure all factor contributing to workability. The slump test was carried in accordance with B.S:1882 PART2:1970.

4.3 Test for Harden Properties of Concrete

4.3.1 Compressive Strength of Concrete

The compression test was conducted according to IS 516-1959. This test helps us in determining the compressive strength of the concrete cubes. The obtained value of compressive strength can then be used to assess whether the given batch of that concrete cube will meet the required compressive strength requirements or not. For the compression test, the specimen's cubes of 15 cm x 15 cm x 15 cm were prepared by using mswa concrete as explained earlier. These specimens were tested under universal testing machine after 7 days, 14 days and 28 days of curing. Load was applied gradually at the rate of 140kg/cm^2 per minute till the specimens failed. Load at the failure was divided by area of specimen and this gave us the compressive strength of concrete for the given sample.

Fig. 6: Compressive strength testing of cube sample.

5. RESULTS AND DISCUSSIONS

As per experimental programme results for different experiments were obtained. They are

shown in table format and graph format, which is to be presented in this chapter.

5.1 Harden properties of concrete (Workability Test)

5.1.1 Slump Test

The Slump test was performed on the MSWA concrete to check the workability of it at different replacements viz. 5 %, 10 %, 15%, 20% and the following results were obtained, according to which it can be concluded that with the increase in % of MSWA from 0 to 20 % , workability decreases. The results obtained for Slump test are shown below in Table. 3.

Table. 3: Results of slump test.

S.No	% of MSWA	Slump value (cm)
1	0%	69
2	5%	64
3	10%	58
5	15%	54
6	20%	47

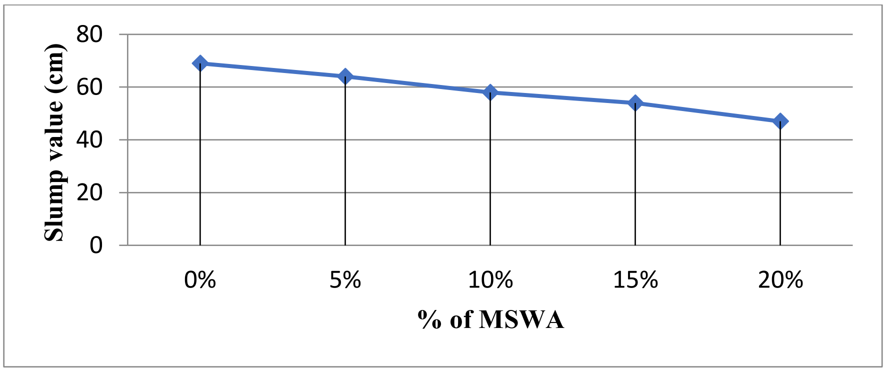

Fig. 7: Slump test results.

The above fig. 7 shows the slump results. It was observed that, the slumps decreased as the MSWA content were increased in the mix. It was suitable for Low Workability mixes used for foundations with light reinforcement. Roads vibrated by hand operated machines.

5.2 Harden properties of concrete

5.2.1 Compressive Strength Test

The compressive strength test was performed on the cubes of size 15 cm x 15 cm x 15 cm to check the compressive strength of MSWA concrete and the results obtained are given in Table. 4.

Table. 4: Results of compressive strength test.

S. No.	% MSWA	Compressive strength of cubes (N/mm^2)		
		7 days	14 days	28 days
1	0	13.9	18.3	24.7
2	5	15.5	22	27.9
3	10	15.4	23.2	25.8

4	15	13.9	20.2	23.1
5	20	12.54	18.5	20.8

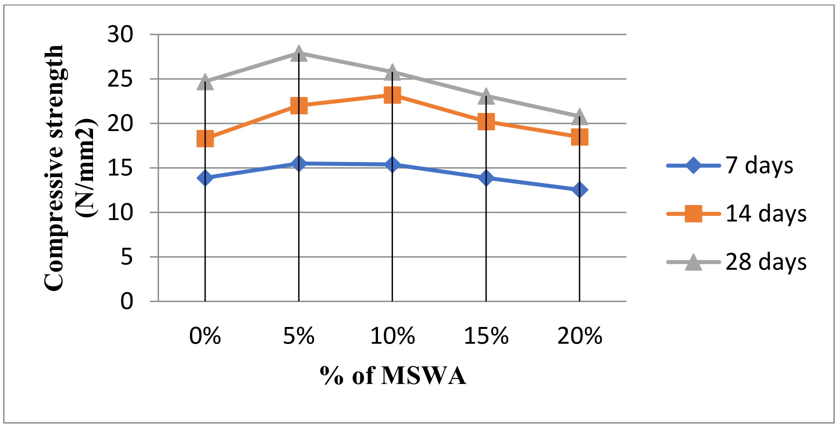

Fig. 8: Compressive strength v/s % of MSWA.

From the above results it was observed that with the increase in percentage of MSWA from 0% to 5% in concrete the compressive strength increases after that decreases.

6. CONCLUSION

The conversion of municipal solid waste by-products into construction materials presents a promising opportunity to address two critical urban challenges: waste management and sustainable building practices. This study has demonstrated that with proper segregation, processing, and testing, several components of MSW—such as plastics, glass, and incinerated organic residues—can be successfully incorporated into construction applications without compromising performance standards.

The results highlight the dual benefit of such an approach: reducing environmental degradation from excessive waste disposal and minimizing reliance on non-renewable construction materials. In addition, the reuse of MSW in construction supports circular economy goals by creating value from waste streams and promoting resource efficiency.

Future work should focus on standardizing processing methods, ensuring material safety, and scaling up pilot applications for commercial use. Policymakers and industry stakeholders must also collaborate to create regulatory frameworks and incentives that encourage the adoption of MSW-based construction materials on a broader scale. With continued research and innovation, turning waste into infrastructure can become a cornerstone of green urban development.

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