Study on The Application of Processed Municipal Solid Waste Ash for Sustainable Construction Materials

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Abstract. The total amount of solid trash produced in India is 160038.9 TPD, according to the Annual Report on Solid Waste Management (2020–21), CPCB, Delhi. Out of which, Tamil Nadu created 13422 TPD of solid waste, of which 9430.35 TPD was processed, and 2301.04 TPD was landfilled. The researchers have been forced to look at alternative processes and materials for the manufacturing of construction materials utilizing processed municipal solid waste ash (PMSWA) due to the increased demand for environmentally friendly and sustainable products. This research work focused on the replacement of fine aggregate by (0%, 10%, 30% and 50%) Processed Municipal Solid Waste Ash (PMSWA) in the Solid Blocks. This research enhances the sustainable material development in the construction industry. SEM study showed that specimens with CTR do not have any cracking on their fracture surfaces, unlike samples without CTR. This study examines the material's physical characteristics, including its mechanical attributes like compressive strength and flexural strength as well as its chemical composition using XRF. It demonstrates that the substitution or addition of PMSWA to construction materials is appropriate, cost-effective, and safe.

1 Introduction

Solid waste is described as undesirable garbage that is left behind after performing a certain purpose. Organic material makes up solid waste, which, if improperly managed, degrades and emits a bad odor. Acute challenges with solid waste management beset the majority of the nation's urban districts. Approximately 1,000,000 MT of solid trash is thought to be produced daily in the nation. Waste production per person in large cities ranges from 0.2 kg to 0.6 kilograms. From the standpoint of preserving public health and maintaining a clean, hygienic environment, solid waste management is crucial. Solid waste management was neglected for many years, which has led to a very low and unsatisfactory level of service. The quality of service is steadily declining even though solid waste management requires 30 to 50 percent of people and resources. Only between 50 and 90 percent of collections are successful, leaving the remaining balance unattended. According to estimates, the cost of collecting, transporting, treating, and disposing of solid trash by urban local authorities ranges from Rs. 500 to Rs. 1500 per tonne. As a result, to improve waste management efficiency, waste collection and disposal must be taken seriously. A solid waste management system's efficacy is further influenced by the bins' strategic placement, estimation of trash production, and onsite storage capacity. Through the implementation of strategic planning processes and laws, many nations have sought

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the beneficial exploitation of PMSWA. To achieve environmental and economic benefits, for instance, some European nations use PMSWA as environmentally friendly building materials in compliance with the environmental standards established by national strategic legislation.
Unsustainable development in materials is one of the most endangered threats to the environment in various countries. Exploiting natural resources are more vulnerable and can be minimized using the recyclable materials like, Nokia uses the recyclable plastics in the manufacturing of mobile phones, waste by products like ashes used in the cement manufacturing etc., Utilization of waste materials like by-products from steel industries, coal industries, municipal solid waste, etc dumped in a large mass and polluting the air, soil and environment. Extensive research work have been already done with the industrial waste by-products, but most of the studies have not focused on the municipal solid waste by-products which exploit the environment in most of the countries. So the Municipal solid waste can be modified and used in the construction materials. The MSW dump can be segregated and converted as an ash, which reduces the landfill pollution like water, air and soil. These ashes can be considered as an alternate and viable option for the manufacturing of bricks and other non-structural elements. The growing demand for the environmentally-friendly and sustainable material has forced the investigators to probe into alternate methods and materials for the production of Processed Municipal Solid waste ash bricks (PMSWAB).

2 Literature Review

In general, the three primary steps of the MSW incineration process are air pollution management, energy recovery, and incineration (APC). The ash that is created is known as PMSWA ash. Local sanitation services collect a stream of garbage known as municipal solid waste (MSW). Hospital medical wastes and recyclable products are typically not included in MSW, which is used to produce power [1, 2]. The majority of municipal garbage is made up of paper and yard waste, both of which can be directly recycled or composted. Currently, the annual amount of MSW recycled in the United States is over thirty percent. Recycling is preferred over any other method of disposal, even if not producing this garbage in the first place is the recommended management strategy for addressing the problem of disposal. After being collected, the majority of MSW that cannot be recovered is usually disposed of in landfills [3, 4]. As an alternative, MSW can be burned directly in waste-to-energy facilities, which produce electricity. Even while MSW, which includes items like food, paper, and wood products, is frequently regarded as a renewable energy source because no new fuel sources are used, it also contains non-renewable materials made from fossil fuels, such as plastics and tyres [5]. MSW is unloaded from collection trucks at the power plant and processed or shredded to make handling easier. Materials that can be recycled are sorted, and the garbage that is left is delivered into a combustion chamber to be burned. Burning the MSW releases heat that is used to create steam that spins a steam turbine to produce energy. The physical and chemical characteristics of PMSWA are discussed, as well as the viability of employing MSW ash as a cement substitute in the production of cement hollow bricks [6].

Globally, the production of solid waste from cities is a threat to both the environment and human health. Burning is recognised as a dependable technological method for the treatment of MSW. It is still challenging to manage municipal solid waste incinerator ashes effectively [7]. Regardless of the fact that the burning process considerably reduces the weight and quantity of waste, there are still enormous amounts of leftovers. Waste is generated in large proportions. Of a 1.3 billion tons of urban solid waste produced worldwide annually and in Belgium, correspondingly, between 130 and 1.3 billion tonnes are burned. From the 400 kT in bottom ash leftovers produced in Flanders, only 102 kT are utilised here; the rest are exported or landfilled because they don't meet environmental standards [8]. To guarantee the environmental safety of AAC with MSWI bottom ash, leaching toxicity was also investigated. The outcomes showed that adding MSWI bottom ash can decrease the density, thermal conductivity, compressive strength, and gas foaming time. Tobermorite formation was significantly impacted by the reactive silica in the bottom ash [9]. Numerous studies have been conducted on the treatment of MSWI fly ash, such as those on glass crystallisation (S/S), thermos-plasticity microencapsulation, and cement-based S/S technologies. Plaster S/S technology is one of the most popular ways to lessen the environmental damage of hard rock contaminations due to its low cost and similarities to its primary components (CaO, SiO2, and Al2O3) [10].

The eco-friendly Green Concrete replacement is required. Recycling and using waste products from many industries, including bio-waste, marine garbage, and e-waste, can add to the strength of green concrete. Nanotechnology has a crucial role to play in both the present and the future when it comes to green buildings. Green Concrete manufacture and application are still in their infancy [11]. Concrete 3D printing uses 3D printing technology to create both structural and non-structural objects out of concrete. It is a quick way of building that doesn't require formwork, requires little effort, and uses less material overall. Concrete's rheological qualities can be controlled along with the print route to create complicated structures like curved walls. In order to lessen the issues with waste recycling and to reduce CO_2 emissions from the production of cement, this technology must be combined with waste materials [12]. Tobermorite, the main thermal product of properly sterilized aerated concrete, has drawn a lot of interest. The addition of MSWIFA prevented the production of fibrous tobermorite, reduced the elongation at break and micromechanical characteristics of tobermorite, and reduced the hardness and elastic modulus of the substance [13]. The USEPA technique 1311 cytolytic activity syphoning process (TCLP) regulatory oversight limits of 2011 were initially not met by the uncooked solid waste from city and county combustion fly ash (FA) sample, but this was before processes significantly reduced its chlorine ions and death metal content, assisting in bringing it into compliance with aforementioned statutory standards. Over 98% of each hard rock was removed. The majority of the remaining material was managed to remove (99.99%), along with the cadmium (Cd) [14].

Incineration is a useful method for reducing the massive amount of non-hazardous, non-recyclable trash (specifically, municipal solid waste, or MSW). Given that disposing of MSW in landfills costs money and causes pollution, incineration may be an effective solution. The resulting bottom ash has a significant deal of potential for use in cementitious products as a substitute for some of the cement. This offers the dual benefits of decreasing landfill and the amount of cement in cementitious products [15]. Sample characterisation is done using FTIR spectroscopy and X-ray powder diffraction. FTIR peaks of calcium-containing phases are assigned using spectral subtraction, and deconvolution is employed to uncover different discrete Si-O peaks concealed inside the single broad FTIR peak [16]. It was discovered that the behaviour for composites comprising cleaned MSWI flying ash and bottom ash reacted mainly in difference of water required and setting time. It was discovered that adding cleaned fly ash and bottom ashes reduced the tensile performance of cement composites, hence the optimum replacement by cleaned MSWI flying ash and bottom ash must be kept to a maximum of 40 wt% and 20 wt%, correspondingly. Finally, it was determined how the business and environment will be affected by the cementitious as they were derived [17]. As just an alkali activator solution, sodium hydroxide (NH) was added to nano silica (NS) at a concentration of six molars while maintaining the alkaline liquid to cement ratio (S:B) for all mixtures at 0.25. Alkali-activated samples were dried out at room temperature (27 °C) and 75% relative humidity [18].

The pH of the environment around the landfill drops below 4, heavy metal leaching will increase. Because of this, waste that was once deemed to be non-hazardous may eventually provide dangerous threats to both people and the environment [19]. Incineration bottom ash significantly raises the yield point and fluidity of new pastes. Incinerator bottom ashes aerated geopolymers feature less gaps as a result of reduced gas bubble growth because of increased strain rate of the paste and reduced bubble coalescence due to higher paste viscosity [20]. It's typical to find extensive periodicals with a sizable readership, like Waste Disposal and Resource, Conservation & Recycling. The proportion of organic waste in municipal solid trash and C&D waste differed significantly across industrialized and developing countries. Casual recycling, ecological design, and sustainability have all grown in prominence as hotspots of solid waste management in emerging countries between the years of 2002 and 2006 [21, 22].

In the construction industry, unsustainable development is one of the most vulnerable threats to the environment in various countries [23-24]. The growing demand for the environmentally-friendly and sustainable material has forced the investigators to probe into alternate methods and materials for the production of Processed Municipal Solid waste ash bricks (PMSWAB). Utilization of waste materials like municipal solid waste dumped ash conserves the natural resources to be an alternate and viable option for the manufacturing of bricks and other non-structural elements. Addition of various percentage of processed municipal solid waste ash, super plasticizers will enhance the strength is the uniqueness of this proposal

3 Materials and Methods

3.1. Materials

3.1.1 Sample selection

The PMSWA ash is taken as a sample. First, the prior solid waste ash was entirely removed while the incinerator was running continuously. After a particular amount of ash had accumulated in the bag dust collector, 20 kg of solid waste ash was then removed and evenly distributed. It was ultimately dried for 24 hours at 105°C to get a constant weight for the sample.

3.1.2. Sample Physico-chemical property

As a sample, 100 g of PMSWA solid waste ash was chosen. Following drying, X-Ray Diffraction was used to determine the percentage concentrations of the primary chemical constituents. Additionally, other physical characteristics of the solid waste ash were assessed using the appropriate instrument. Table 1 displays the conclusions from the analysis. According to the test results, the primary elements in processed municipal solid waste ash are CaO, SiO2, Al2O3, and Fe2O3.

Table 1. Primary elements and physical characteristics of a sample of PMSWA.

Chemical Components							Physical performance			
SiO_2	Fe_2O_3	Al_2O_3	CaO	MgO	SO_3	Cl^-	Moisture Content (%)	Density (kg/m^3)	Specific Surface Area (m^2/g)	Pore Volume (cm^3/g)
28.45	6.23	8.23	25.78	4.23	13.45	16.23	0.6-2.0	3456	6.89	0.034

3.1.3. Aggregates

M Sand is used in this study as a fine aggregate, and this can be replaced with various percentages of PMSWA. Typical sand's particle size was analysed. More than 95% of the total content can flow through a sieve with a 0.25 size opening. Standard sand contains more than 96.0% silicon oxide. Additionally, the sediment % is less than 0.2 percent and loss on ignition (LOI) of sand should be less than 0.4%.

3.1.4. Cement

A cement is a binder, a chemical substance used for construction that sets, hardens, and adheres to other materials to bind them together. Chemical Composition of OPC 53 grade is shown in Table 2.

Table 2. Chemical composition of OPC

Sl. No	Chemical Composition	% OPC
1	CaO	61.5
2	SiO2	21.2
3	Al2O3	6.2
4	Fe2O3	3.4
5	MgO	3.1
6	SO3	2.4
7	Gypsum	2.2
8	LOI	1.8

3.2 Methods

3.2.1. Heavy metal contents of solid waste ash

First, the HNO3eHFeHClO4 technique was used to weigh 100 g of materials for degradation. Metal ions in the liquid of degradation might be translated from the solid waste ash. ICP-MS analysis of the content of heavy metals in the digestion solution was then possible (the instrument was an ICP-MS of the "SPECTRO MS" type made in Tamil Nadu by Spectro analytical instruments co., LTD.) Cu, Zn, Cr, and Pb are more abundant in solid waste ash, which has a wide range of heavy metal levels.

3.2.2. Washing pre-treatment

The introduction of the water washing procedure as a pre-treatment approach for the removal of sulphates and chlorides in PMSWA. After 0.5 hours of interaction with water at room temperature, the sulphates and chlorides were discharged in a washing pre-treatment procedure with a liquid-to-solid ratio of 5:1. The pre-treated ash was cleaned, and then it was dried to reduce the moisture content.

3.3 Specimen preparation

Sand cement is a crucial component of the building industry's raw materials. Sand is a granular substance that occurs in nature and is a type of fine aggregate made up of tiny pieces of rock and mineral. In this investigation, binding substances like Ordinary Portland Cement (OPC) and High-Range Water Reducer (HRWR) were used, namely SP-1(234), a poly amino group with a long lateral chain that complies with ASTM C494 Type F. It was utilised to prepare the Solid Block specimens and was purchased from a nearby store.

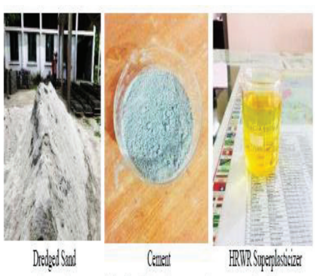
Table 3. Chemical composition of M Sand and PMSWA.

Sl.No	Chemical composition	% M Sand	% PMSWA
1	C	1.68	8.2
2	O	48.25	51.8
3	Mg	2.25	0.35
4	Al	8.28	12.89
5	Si	18.26	20.38
6	K	2.81	0.80
7	Ca	3.65	0.56
8	Ti	1.85	1.13
9	Fe	9.99	2.21
10	Na	2.98	1.68

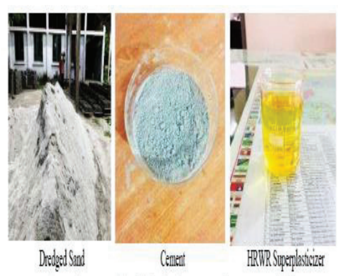
The OPC was bought on the open market in the area. The chemical makeup of M-sand and PMSWA is shown in table 3 and can be determined using the gravimetric method. Gravimetric analysis is a quantitative chemical analysis technique that transforms the desired constituent into a substance with a known composition that has been weighted and separated from the sample.

3.4 Mixing process

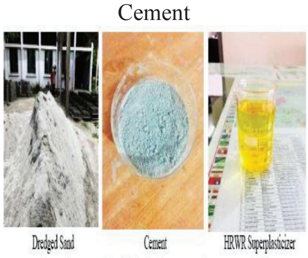
In a hydraulic press machine, solid blocks of sand cement were produced. The hydraulic machine's compaction pressure is at 2000 PSI. Blocks were produced in the customary dimensions of (9.0"x4.5"x3.0") for solid blocks.



Cement



HRWR



M Sand

PMSWA

Fig.1. The raw materials of Cement, M Sand, HRWR Super plasticizer and PMSWA.

Figure 1 shows the components of a block, which are PMSWA, cement (OPC), HRWR and water. The weight ratios of these raw components was 1:5. Fine aggregate has been replaced by 0% as (A), 10% (B), 30%(C) and 50%(D) of PMSWA. Based on field practises, the ratios were chosen. The SP dosage was maintained at 200 ml per cement bag, and the water-to-cement ratios were maintained as (0.25 to 0.28). Use SP-234 to test the specimen for each W/C ratio. Three steps are typically involved in the production of blocks: 1) combining the ingredients in the pan mixture 2) Casting in the mould 3) The mould must receive hydraulic compaction pressure of about 2000 psi from a hydraulic compaction pressure machine before the moulded mixture material can be transported to drying to give covered internal curing into polyethylene. Steps two and three involve the placement of mixed materials in moulds. The blocks were then placed in the field for 7, 14, 28 and 56 days to properly cure.

3.5 Characteristics of the Superplasticizer

In its natural state, SP-234 is a liquid with a dark brown colour due to the poly amino-based group. It has a sedimentary gravity of 1.170–1.190 at 270°C and no chloride content. Improved water efficiency during mixing and delayed initial setting of concrete mix are two benefits of SP 234. Increases in density, workability, and strength are provided. It is compliant with ASTM C 494 F.

3.6 Curing of the specimens

The mortar samples were compressed and shaped in a cubical mould with solid sand cement blocks measuring (9.0"x4.5"x3.0"). Standards from ASTM (C192/C-192M) for sampling, curing, and testing were used. For this cure, we merely used water spray. Figure 2 displays water spray curing on PMSWA solid blocks.
The block samples were tested for compressive strength at curing ages of 7, 14, 28 and 56 days after being damp cured up until that point. About three hours before testing, the samples were taken out of the water and maintained in the lab's air-dry environment. All block samples underwent testing up to the failure point in accordance with ASTM C-39. The compressive strength test specimen of the investigated block is shown in Fig. 3 below. Equation is used to determine capacity. Area of loading x Load at Failure = Compression Capacity UTM machine compression strength test Figure-3 PMSWA Solid Block.

Fig.2. Water Curing of PMSWA block.

Fig.3. Compressive strength test by UTM machine of PMSWA Solid Block.

3.7 Water absorption

In order to assess the information about the pore spaces as a result of ingredient settlement, compactness, and mixing contents, the water absorption capacity was assessed. All of the surrogate samples' water absorption was assessed at 7, 14, 28 and 56 days of curing. As seen in fig. 4, specimens were maintained in a fully submerged condition. The commonly used equation below, which is advised by ASTM C 1585-13, was used to compute the amount of water that would have been absorbed after immersion: Water absorption percentage (W) is [(WS - WD) / WD] *100, Where WD = Weight of oven-dried specimen and WS = Weight of specimen in fully saturated condition (kg), respectively (kg).

Fig.4. Water absorption of PMSWA Block.

4 Results and Discussions

4.1. Compressive strength

Numerous studies have demonstrated that when the compressive strength of the unit (fbl) grows, so does the compressive strength of masonry prisms (Fig. 5). The connection between prism strength and block strength appears to be essentially linear within the range of typical block strengths (10–30 MPa). Higher block strengths within the database, where the relationship appears to become slightly non-linear, are exempt from this linear trend. Deep-beam analysis has been used to explain the vertical cracks in the webs that are seen in face-shell bedding. It is not unexpected that a somewhat non-linear relationship between prism strength and block strength is found given that prism compressive failure is linked to tensile cracking in the prism and that the tensile strength of concrete is related to compressive strength in a non-linear manner.

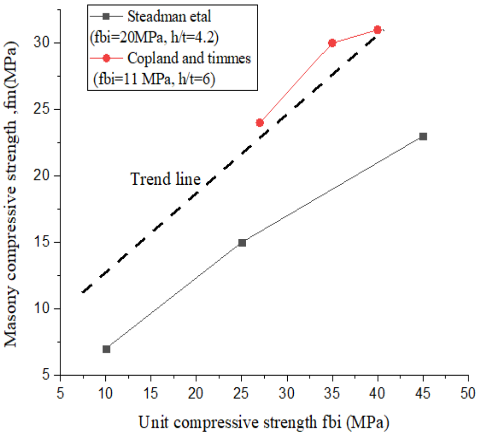


Fig.5. Effect of unit strength on the compressive strength of un-grouted PMSWA block masonry.

4.2 Effect of mortar strength (fmr)

Numerous studies have shown that the kind and mortar strength (fmr) have an impact on f0 m. Less induced lateral tensile prisms, which are the primary culprit in masonry prism collapse, are caused by stronger mortar. Although the overall trend indicates an increase in f0 m with the mortar strength, Fig. 6 shows that there is significant data scatter when mortar strength is plotted versus f0 m.

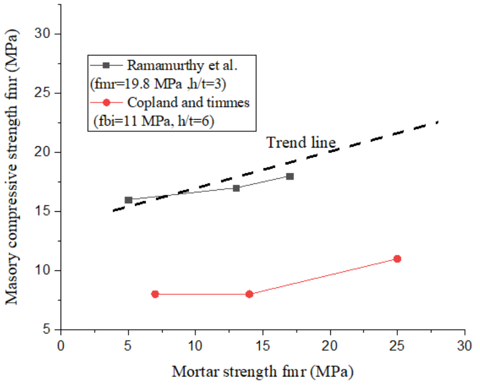


Fig.6. Effect of mortar strength on the compressive strength of ungrouted PMSWA block masonry.

4.3. Characteristics of Chemical

The solid waste ash's minor, trace oxide, and major compositions were examined by XRF (Table 4). The features of the municipal solid waste feed and the combustion system affect the chemical content of solid waste ash.

Table 4. Oxides in the M Sand and PMSWA composition.

Sl.No.	Chemical constituent Name	Chemical constituent Formulae	Oxides Composition in %			
			A	B	C	D
1	Silicon Oxide	SiO2	54.23	55.21	53.21	52.12
2	Aluminium Oxide	Al2O3	8.5	8.65	6.23	6.2
3	Iron Oxide	Fe2O3	19.32	19.23	9.67	7.09
4	Calcium Oxide	CaO	4.23	5.76	13.21	11.23
5	Magnesium Oxide	MgO	3.23	2.12	1.76	1.23
6	Sulphur Oxide	SO3	1.3	1.23	1.34	1.23
7	Potassium Oxide	K2O	2.12	3.24	3.23	2.34
8	Sodium Oxide	Na2O	1.67	1.76	1.56	1.23
9	Manganese Oxide	MnO2	1.45	1.56	1.67	1.65
10	Titanium Oxide	TiO2	1.67	1.67	1.56	1.45
11	Loss on Ignition	-	12.12	13.12	13.98	12.56

4.4 Qualities of Plasticity

According to Table 4, the liquid limit for samples A and D was 48 percent, B was 43 percent, and C was 40 percent. The plasticity index for specimens A and B, 0% for specimen C, and 9% for specimen D, which are all within the limit of not more than 12%, was larger than 35%. For specimens A and B, the percentage passing the BS sieve 200 was likewise higher than 35%, however, it was lower for samples C and D. The PMSWA solid waste ash may not be utilized directly as the base and sub-base material as required by the FMW&H specification because of these characteristics of the material, which render it inappropriate.

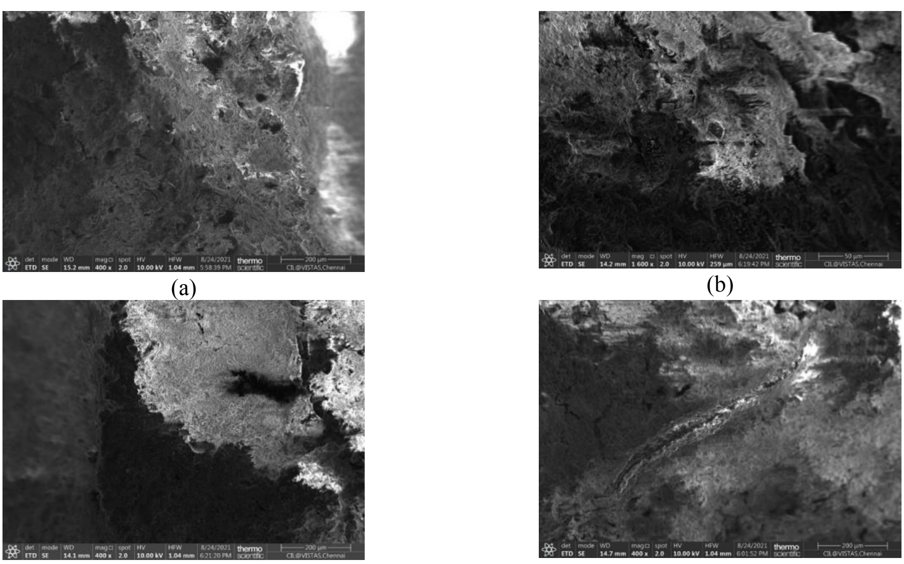
Table 5. M-Sand and PMSWA Index Qualities.

Sl.No.	Properties	Oxides Composition in %			
		A	B	C	D
1	Natural Moisture (%)	19.23	14.29	20.12	20
2	Specific Gravity	1.62	1.87	2.12	2.21
3	Liquid Limit (%)	46.12	44.23	42.12	40.21
4	Plastic Limit (%)	41.23	36.98	35.02	36.21
5	Maximum Dry Density (Mg/m^3)	2.12	3.21	4.13	4.12
6	Optimum Moisture Content (%)	9.1	9.2	9.2	9.7
7	Coefficient of Permeability (mm/s)	$5.3x10^{-3}$	$5.5x10^{-3}$	$6.0x10^{-3}$	$6.2x10^{-3}$
8	Group Index	2	2	3	3
9	AASHTO Classification	A-5	A-5	A-4	A-4
10	UCS Value (kN/m^2)	245	256	267	278
11	CBR Value(%)	14	13	14	14
12	Plasticity Index (%)	9	9	9	9
13	Linear Shrinkage (%)	3	3.5	3.5	4
14	% Passing IS Sieve	40.2	48.3	32.1	45.4
15	Colour	Blackish Grey	Blackish Grey	Blackish Grey	Blackish Grey

4.5 Characteristics of Compaction

The density and the moisture levels at which the density was compressed both affect a number of the engineering characteristics of the PMSWA samples. Table 5 displays the moisture-density correlations for samples A, B, C, and D. When taking into account the impact of compaction on PMSWA specimens, the results demonstrate the variation of density with water content. There was a steady increase in dry density with the rise in water content before a decrease in dry density at the 4th and 5th trials, but with an increase in moisture composition as it is usually with an increase in moisture-density in normal moisture-density connection.

4.6 SEM Analysis



(a) (b) (c) (d)

Fig.7. SEM surface analysis.

The fracture surface of the cement blocks with both degraded and unreduced limestone residues was examined using SEM, and significant variations were found. The fracture outcomes for samples of cement blocks with 30% vol. limestone incorporations are shown in Figures 8(a) through (d). In degraded samples put through the durability test, Figures 8(a) and (b), it was confirmed that the fractured surface showed via the matrix/aggregate transition zone, high adhesion and also a denser matrix with few voids and pores. The increased volume of the cement's hydrated components in comparison to the amount covered by the anhydrous stages could be the cause of this drop in porosity. Figures 8(c) and (d) for the non-degraded samples that were not subjected to the durability test show that the sample's fracture surface shows through the matrix/aggregate transition zone evidence of low adhesion, which justifies the presence of the microcracks and pores denoted by the arrows.

5. Conclusion

The PMSWA is used as a replacement material for fine aggregate with varying percentages analysed in this research. The amount of cement, the PH value of the leaching liquid, the compressive and flexural strengths of the solid waste ash-cement compound under the cement solidifying solid waste ash technique were just a few of the many aspects that were thoroughly examined. This solid block will definitely act as a sustainable and eco-friendly material. The inferences that can be made are as follows:

- Ash from municipal solid waste can be used to partially replace fine aggregates in brick materials. The physical characteristics and intended gradation of aggregate-solid waste ash mixtures comply with the standards. The chemical composition for the various replacements can be analysed using XRF.
- The majority (>80%) of Cl_ and SO3 in the PMSWA can be removed through water washing pre-treatment, but soluble salts of these substances can quickly and easily contaminate the environment.
- Heavy metals in PMSWA can be treated using the cement solidification and stabilization process, which also greatly lowers the leaching concentrations, particularly for Pb and Cd.
- The leaching levels of heavy metals in the solid waste ash-cement compound rapidly decrease and reach a very low level under alkalescent conditions as the PH value of the leaching liquid increases. Additionally, as the vibrating leaching duration is extended over a specific period, the leaching levels of heavy metals in the original ash and solid waste ash-cement compound rise and stabilize.
- SEM analysis was used to look at the fracture surface of PMSWA bricks that contained both reduced and unreduced limestone residues.
- PMSWA bricks are used because of their various advantages and affordability. Bricks made of this 50% fly ash are preferable for framed structures. This is so that framed structures may be constructed, which calls for strong foundations and concrete with a high strength.

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