Utilizing Eggshell Powder and Municipal Solid Waste Ash for Eco-Friendly Construction

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ABSTRACT

With rapid industrialization, the accumulation of industrial by-products has become a significant environmental and economic challenge, particularly due to disposal issues such as landfilling. Among these waste materials, eggshells are a major biodegradable by-product generated in large quantities by chick hatcheries, bakeries, and fast-food restaurants. Improper disposal of eggshell waste can lead to ecological contamination, necessitating effective waste management strategies. Given that eggshells primarily consist of calcium carbonate, they hold potential as a supplementary material in concrete production, contributing to sustainable construction practices. Globally, approximately 90 million tons of eggshell waste are produced annually, with India alone producing 77.7 billion eggs in 2010-2011. Similarly, municipal solid waste incineration ash (MSWA) has been extensively studied as an alternative material in concrete manufacturing. Among various types of incineration ash, bottom ash is considered the most suitable for concrete applications due to its favorable composition and availability in large quantities. The incorporation of MSWA in concrete not only reduces waste accumulation but also provides an opportunity to enhance the sustainability of the construction industry. Cement production is an energy-intensive process and a major contributor to greenhouse gas emissions, particularly CO_2. By reducing the demand for cement through the use of alternative materials such as eggshell powder (ESP) and MSWA, natural limestone reserves can be conserved, energy consumption can be reduced, and overall environmental pollution can be minimized.
This study focuses on the development of M20 grade concrete with the partial replacement of cement using 0% to 20% MSWA and 5% ESP by weight of cement. Experimental investigations were conducted to assess the workability, compressive strength, and flexural strength of the prepared concrete samples. The results indicate that an optimal blend of MSWA and ESP in concrete can achieve comparable or improved mechanical properties while promoting environmental sustainability. The successful integration of eggshell powder and municipal solid waste ash in concrete presents a viable solution to waste management issues while reducing reliance on conventional cement. This eco-friendly approach not only enhances the performance of concrete but also contributes to the development of greener and more sustainable construction materials.

Keywords: egg shell powder (ESP), municipal solid waste ash (MSWA), workability, tensile strength and compressive strength.

1. INTRODUCTION

The incineration of municipal solid waste has significant benefits as it can reduce the volume and the mass of the waste by about 90% and 70%, respectively. Municipal solid waste is collected and burned in an incinerator; the by-products of the combustion process are collected. Bottom ash typically accounts for 80% of the whole amount of by-products in the MSWI plants. Municipal solid waste incinerator bottom ash is the ash that is left over after waste is burnt in an incinerator. This ash contains glass, brick, rubble, sand, grit, metal, stone, concrete, ceramics and fused clinker as well as combustive products such as ash and slag. Cement and aggregate, which are the most important constituents used in concrete production, are the vital materials needed for the construction industry. This necessity led to a continuous and increasing demand for natural materials. Parallel to the need for the utilisation of the natural resources emerges a growing concern for protecting the environment and need to preserve natural resources, by using alternative materials that are either recycled or discarded as a waste. One of the possibilities is to use Municipal Solid Waste ashes in concrete production.

Cement and aggregate, which are the most important constituents used in concrete production, are the vital materials needed for the construction industry. This inevitably led to a continuous and increasing demand of natural materials used for their production. Parallel to the need for the utilization of the natural resources emerges a growing concern for protecting the environment and a need to preserve natural resources, such as aggregate, by using alternative materials that are either recycled or discarded as a waste.

2. LITERATURE REVIEW

Population growth, booming economy, and rapid urbanization have greatly accelerated the solid waste generation all around the world. The annual global generation of solid waste has recently approached 17 billion tons and is supposed to hit 27 billion tons by 2050 (Laurent et al., 2014). This issue is of stinging concern to the nations, municipalities, and individuals, as it can cause significant damages to human health, natural resources, and ecosystems. Therefore, the concept of adopting green chemistry and technologies for environmental sustainability has been increasingly recognized and included in recent years.

Most notably, the traditional concept, in which waste is regarded as pollution, has been progressively shifting towards the new perspective that waste is treated as a resource. This undoubtedly can support societies to become more sustainable. For instance, the energy generated in certain thermal processes of waste materials can trim the energy generation services through conventional technologies. Likewise, the reuse or recycling of certain solid waste materials, such as metal, plastic, and paper can conserve the source of the corresponding virgin materials.

Against this scenario, the research of recycling solid waste materials into the production of construction materials has been carried out extensively (De Carvalho Gomes et al., 2019). These endeavors are intended to slim down the volume of solid waste, and also trim down the mounting demand for natural resources in the construction industry. Heretofore, impressive achievements relevant to this field have been attained. For example, Huang et al. (2007)

reviewed the successful utilization of solid waste materials (i.e., steel slag, waste glass, tires, and plastics, etc.) for the development of asphalt pavements.

Meng et al. (2018) summarized the existing research work on recycling a range of solid waste materials in the production of concrete blocks, including crushed brick, waste glass, recycled concrete, ceramic waste, and tile waste, etc. Luhar et al. (2019b) outlined the possible use of various kinds of aquacultural and agricultural farming waste as supplementary materials in concrete. Besides that, some attracting achievements have been made in recycling solid waste materials for the manufacture of geopolymer composites. Geopolymer, namely alkali-activated material, is usually derived from the chemical reaction between aluminosilicate precursor materials and alkaline activators, being widely regarded as an alternative to ordinary Portland cement (OPC) (Provis, 2013). The past three decades have witnessed the rapid development of geopolymer through academic pursuit because of its excellent performance in various fields.

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).

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).

More to the point of utilizing MIBA as a precursor or gas-forming additive, researchers have evaluated the feasibility of the application of MIBA to substitute the aggregate in geopolymer composites. The study of Gao et al. (2017) was on this aspect. Here, MIBA was employed as a substitute for a maximum of 50 % fine aggregate (by volume) in geopolymer mortar. Although MIBA negatively affected the strength for its porous and fragile structure, no expansion and cracking was observed due to the metallic aluminate from MIBA. Eventually, the compressive strength of 35–56 MPa can be achieved, suggesting wide application potentials and high reuse rates of MIBA in geopolymer composites. Furthermore, the leaching behavior of formed products met the relevant legislation, confirming the advantages of using geopolymer composites again.

Manzoor Ahmad Allie (2018) In this paper, it is studied that quality of construction material is an important issue which enhances the stability of the structure, an attempt has been made to study the possibilities of using Eggshell powder in paver block. Cement was partially replaced by Eggshell Powder at 5% intervals from 0% to 25% by the method of replacement by weight. The paver block Curing process is done for 7 days and 28 days, after curing it is checked for its Compressive Strength and flexural strength. It was noted that 13.4% increase of compressive strength at 10% replacement of Eggshell Powder. Flexural strength was also 19.5% increased at the same 10% replacement of Eggshell Powder. The result showed the Eggshell Powder can gives more strength if it was replaced as 10% of cement.

Pradeep Sharma (2018) In this study performed to decide the very best excellent percent of eggshell powder as partial cement replacement. The creation industries are looking for 'alternative material that may lessen the Construction cost. Over 5% of world CO_2 emissions can be credited to Portland cement manufacturing. Demand for cement maintains to develop different ESP concretes were established through replacing 4 to 16% of ESP for cement. Concrete performs the important thing function and a large quantity of concrete is being implemented in every introduction exercise. The egg shell commonly that are disposed, is used as an exchange for the cement for the reason that shell is manufactured from calcium. An egg shell is utilized in first rate combos to discover the feasibility of the use of the egg shells as an exchange to cement. Intention of this task is to prevent the pollution of environment with the aid of the usage of the wrong disposal of the eggshell waste, a live from eggshells domestic waste which includes schools, restaurant, bakeries, homes and rapid food accommodations, via the use of the usage of it as an additive fabric inform of ash & powder in traditional concrete with grade M35 because it's far usually utilized in manufacturing internet websites.

N. Parthasarathi (2017) In this paper, concrete is broadly used for the structures. Cement is main material in concrete but due to high demand of cement is costly. And to minimize the cost of structure, alternate material is required to manage the wastes in eco-friendly way. The intention of this research work is to apply the egg shell powder constrained extra of cement. Eggshell powder is changed by using 5%, 10% and 15% weight of cement. An experimental study proves the strength capabilities consisting of spilt tensile strength take a look at that is decreased with addition of eggshell powder, compressive strength test and flexural strength take a look at which can be increased up to 15%.

Amarnath Yerramala (2014) In this paper, it describes the usage of poultry waste in concrete thru the improvement of concrete and studied the Properties of concrete with eggshell powder (ESP) as cement alternative. Different ESP concretes had been advanced through replacing 5-15% of ESP for cement. Test are taken, compressive energy and split tensile strength take a look at turned into better than normal concrete for 5% of ESP alternative and it had lower strength than normal concrete with greater than 10% of substitute on the age of 7 & 28 days. The results proven that irrespective of ESP percentage substitute there has been proper relationship among compressive strength and split tensile strength.

3. PROPOSED SYSTEM

3.1 Objective

The objectives of the work are stated below:

i) To develop mix design methodology for mix 20 MPa

ii) To study the effect of adding different percentages (0% - 20%) of MSW ash and 5% Eggshells powder 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.
v) To determine the Tensile strength of beams at 28 days.

3.2 Methodology

1. Collect the egg shells from, by blending process the egg shell powder (ESP) was obtained. The ESP and sieve with 75microns IS sieve, passed ESP used for cement replacement. Find out the fineness modulus and specific gravity tests for ESP.
2. The MSWA prepared in the month of March 2023 in a manual incineration process at Ghatkeshar Municipal Solid waste dampage area. The incinerator ash has been sieved and metal pieces has been removed manually. The generated ash from manual incineration involves a wide range of particles size; only the fraction less than 75 microns has been used in this work. The ash has been dried before experiments. Find out the fineness modulus and specific gravity tests for MSWA.
3. Find out the physical properties of Coarse aggregate, Fine aggregate, cement.
4. Design mix design of M20 grade concrete. And calculate the mix proportions for individual mix.
5. Partial replacement of cement with 5% ESP with varying percentages MSWA of (0% - 20%) in the preparation of concrete.
6. Perform the workability, compressive strength and tensile strength tests on conventional and MSWA-ESP based concrete. Compare the values and find out the optimum percentage of MSWA-ESP replacing by cement.
7. Conclusions.

3.3 Experimental program

To achieve the specified objectives (section 3.1) the following test program was planned and presented in the table 3.1. The number of specimens allotted for each test was included in the same table.

Table 3.1: Experimental Program

Type of test to be conducted	Behavior to be identified	Specimen	Size	No
Slump cone test	Fresh concrete properties	-	-	
Compression test	Compressive strength	Cube	150 X 150 X 150 mm	54
Flexural strength test	bending strength	Beam	300 dia X 100 mm height	18

4. 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.

4.1 Fresh properties of concrete (Workability Test)

4.1.1 Slump Test

The Slump test was performed on the ESP-MSWA based concrete to check the workability of it at different replacements viz. 5%-0%, 5%-5 %, 5%-10 %, 5%-15%, 5%-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 increases. The results obtained for Slump test are shown below in Table 4.1.

Table 4.1: Results of Slump test

S. No	ESP%-MSWA%	Slump value (mm)
1	0% - 0%	120
2	5% - 0%	125
3	5% - 5%	132
4	5% - 10%	140
5	5% - 15%	146
6	5% - 20%	149

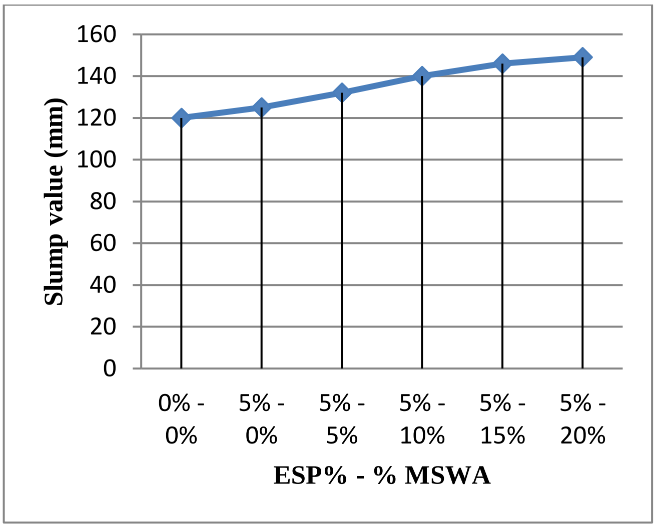


Fig 4.1: Slump test results

The above figure 5.1 shows the slump results. It was observed that, the slumps increased as the MSWA content were increased in the mix. It was suitable for Medium Workability mixes.

4.2 Harden properties of concrete

4.2.1 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 4.2.

Table 4.2: Results of compressive strength test

S. No	ESP%-MSWA%	Compressive strength of cubes (N/mm^2)		
		7 days	14 days	28 days
1	0% - 0%	14	17.89	20.2
2	5% - 0%	16.4	19.2	23.2
3	5% - 5%	17.3	20.1	24.4
4	5% - 10%	19.5	22	25.1
5	5% - 15%	20.7	22.8	26
6	5% - 20%	18.4	21.3	23.7

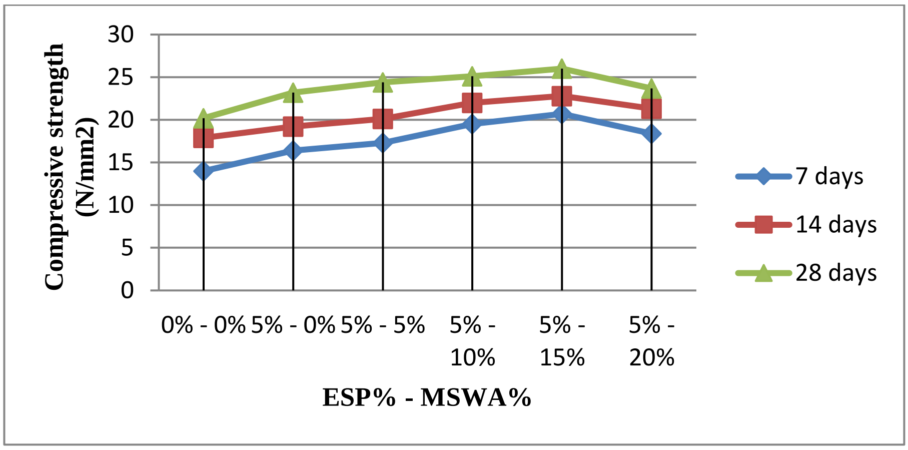


Fig 4.2: Compressive strength

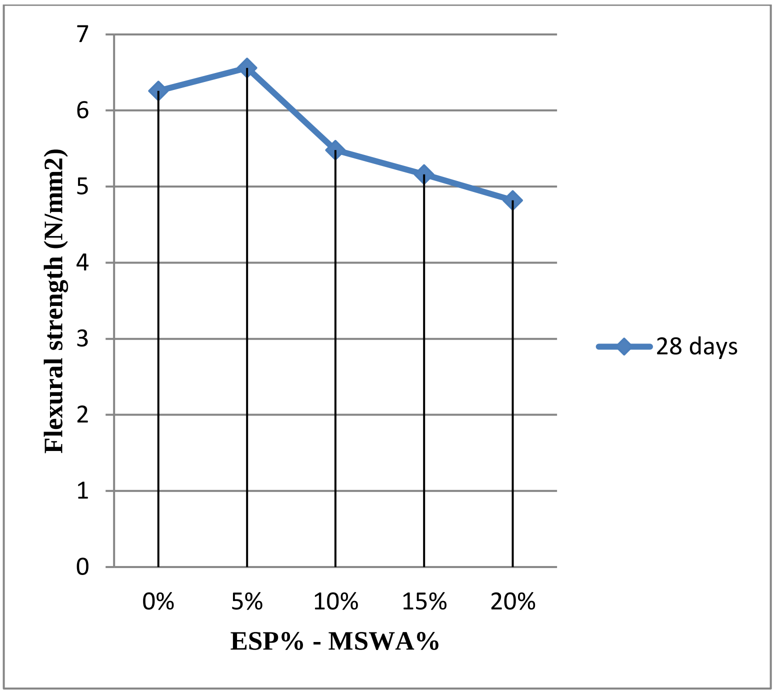
From the above results it was observed that with the increase in percentage of ESP -MSWA from 5% - 5% to 5% - 15% in concrete the compressive strength increases after that decreases. The variation in compressive strength with respect to the given percentage of ESP - MSWA is shown in fig 5.2.

4.2.2 Flexural Strength Test

The Flexural test was performed on the beams of size 50 x 10 x 10 cm to check the flexural strength of the MSWA concrete and the results obtained while performing the flexural test on UTM are given in Table 5.3.

Table 4.3: Result of flexural strength

S. No	ESP%-MSWA%	Flexural Strength for 28 days (N/mm^2)
1	0% - 0%	2.1
2	5% - 0%	2.36
3	5% - 5%	2.5
4	5% - 10%	2.62
5	5% - 15%	2.74
6	5% - 20%	2.42



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From this study, it can be summarised that a replacement of up to 5% of ESP with 15% of MSWA can be made safely in concrete members.

5. CONCLUSION

Based on the results obtained in this project, it is concluded that the partial replacement of cement with eggshell powder (ESP) and municipal solid waste ash (MSWA) can be effectively used in concrete production. One of the key benefits of this replacement is the significant reduction of solid waste accumulation, thereby addressing public disposal concerns. Experimental investigations on M20 grade concrete with a 5% ESP and 15% MSWA replacement showed that the concrete attained a compressive strength of 26 MPa, with an increase of 28.7% in compressive strength and 30% in flexural strength compared to conventional concrete. This demonstrates that replacing 20% of cement (5% ESP + 15% MSWA) in standard concrete construction is not only feasible but also economically and environmentally beneficial. Various studies, including this research, confirm that ESP and MSWA enhance concrete workability and mechanical properties such as compressive and flexural strength, making them suitable for sustainable construction practices. While untreated MSWA and ESP do not fully meet conventional concrete admixture standards, the prepared concrete exhibited acceptable properties, including excellent frost resistance. Although the relatively low content of MSWA in the mix ensures a balance between ecological concerns and material performance, achieving higher replacement percentages without compromising strength would require further treatment of the ash, potentially increasing costs. The utilization of ESP and MSWA in concrete not only presents an eco-friendly alternative to cement but also helps in addressing waste disposal challenges, making it a practical and sustainable solution for the construction industry.

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