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Original Research Article

MECHANICAL AND DURABILITY STUDIES ABOUT THE USE OF MUNICIPAL SOLID WASTE LANDFILL IN CONCRETE

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Abstract

Landfilling is the most common and cheapest method of waste management practice in India. Municipal Solid Waste Landfills (MSWL) became a nuisance affecting the health, hygiene, sanitation and aesthetics of the surrounding area. Aggregates occupy almost 70% of concrete, so replacing waste materials with them could be a rewarding choice. In the current work, an experimental investigation is being carried out to test the addition of MSWL as a substitution with fine aggregate for concrete production. Out of the different aged samples available at the dumpsite, the most aged sample is chosen for experimental investigations according to the basic physical properties. Concrete mixes, with 0%, 4%, 5%, 7% and 10% partial replacement of fine aggregate with MSWL are tested for mechanical properties such as compressive strength, split tensile strength, flexural strength, and non-destructive test and have proved to be a partial substitute for fine aggregate. Durability studies such as water absorption, acid attack and sulphate attack also gave better experimental proof for the sustainable reuse of this waste material. The research reveals 5% replacement is the optimum considering all the test result values. The paper leads to advanced research for the suitability of the material in the construction industry.

Keywords: concrete production, sustainable concrete, municipal solid waste landfill, aggregate replacement, strength, mechanical properties

1. INTRODUCTION

It is estimated that the generation of Urban Municipal Solid waste will be around 165 million tonnes in 2030 due to rapid economic growth and consumption pattern change, according to Solid Waste Management Rules, 2016. India, being the most populated country in the word and by considering the population explosion being a primary factor, it is directly proportional to the amount of waste generation. So the amount of landfilled material will increase day by day. It is high time to identify the reuse of

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landfill material without making health hazards to the users. The use of Municipal Solid Waste Landfill (MSWL) material in construction industry is one of the research projects in recent times. MSWL can be used in the construction industry in various ways like MSW bottom ash, as an admixture, solidification material, embankment material etc.

Concrete, being the most popular artificial material, can be utilized for all types of construction work and an exceptionally versatile building and pavement material. The availability of natural sand and M sand is getting reduced day by day. The utilization of recycled materials is one of the seven principles of sustainable construction. There is a need in the new era that new material to be used, as a replacement for conventional ingredients of concrete should be identified. The use of recycled and waste materials in concrete pavements not only reduces the environmental impact but also provides economic construction materials. Some of such waste materials include scrap tyres, recycled aggregate, recycled concrete, crushed brick, construction demolished wastes, ceramic tiles, plastic wastes, agricultural waste like coconut shell, almond shells etc. The use of these materials, in addition, to enhancing environmental advantages, also reduces the cost of concrete production.

Mysuru district, Karnataka is a well-known and favourite place of tourists. It is blessed with so many tourist attractions like Mysore Palace, Brindavan Gardens, Chamundi Hill etc. All the Municipal waste is brought to a dumpsite situated at Vidyaranyapuram which is about 8 km away from main city. This site is being used for dumping from last 12-years which has an accumulated waste of about 250000cum. The dumping is done in 3-stages concerning its age. The samples were available with 12-year, 10-year and 8-year ages at dumpsite in ready. The younger aged samples have been using as fertilizers. The landfill is creating both hygienic and mental problems for all the people staying near to the dumpsite. It will be helpful for the community if the landfill material can be reused as a construction material. The use of MSWL in cement concrete production is one the key initiatives of the present work. The aged samples looked like black soil with some impurities like pieces of glass and cloth, small stones etc. After sieving, these impurities may be removed and air-dried. The sample can then be directly used in concrete production as a replacement for fine aggregate. The present paper is aimed at the partial replacement of municipal solid waste landfill material in concrete. Here mechanical properties and durability of the mixes are investigated with different MSWL material proportions.

2. LITERATURE REVIEW

The application of ceramic waste and coal waste in roller compacted concrete pavement (RCCP) had increased all the mechanical properties [1]. Mechanical properties such as flexural, splitting tensile, and compressive strengths were increased by 14, 39, and 20%, respectively with 15% of ceramic waste at 90 days of curing. They concluded with the optimal recycling rate of ceramic waste material as 10, 15, and 20% as replacement of coarse aggregates. Another study [2] replaced cement with rice husk at various proportions of 5%, 10%, 15% and 20%. The strength of the concrete increased by 7.07% at 90 day specimen. A concrete mix was developed by using Toothpaste Industry Sludge (TIS) as partial substitute of cement and fine aggregate [3]. There was no change in compressive strength with different ages till 15% replacement of sand with TIS. Further addition of TIS to 20 and 25% replacement of sand, results in decrease of strength as 13% to 25% respectively. An optimum composition containing 10%

of polyethylene terephthalate (PET) and 3% nano silica was investigated, in which the all the mechanical properties were increased compared to the control concrete [4]. Another experiment [5] with eggshell as a fine aggregate replacer along with silica fume and fly ash addition in concrete was done and with 10% addition of eggshell powder had increased the compressive strength by 18.01%.

It is appropriate for the current study to view some applications of MSWL in civil engineering applications. A service road was built using cement stabilized MSW at the Karadiyana landfill, Sri Lanka [6]. The study was to ascertain its suitability of MSW for use as a sub base material in the landfill site itself. Atterberg Limits shows that the MSW sample lies in A-line and is classified as silty clayey sand (SM-SC). The sample is stabilized with cement and geotechnical properties were improved. They have revealed that 5% stabilization with cement was enough to reuse MSW as subbase material. The engineering properties of MSW material [7] have proved measurement and interpretation of the properties for the use in engineering applications. They inferred that an internationally accepted test standards are required to allow interpretation of published results. Also heavy metals leaching behaviour of MSW landfill was studied for long term, in the cement composites made with bottom ash from municipal solid wastes incineration [8]. The study emphasised that content of heavy metal concentration in the leachate were low compared to the standard limits. They inferred that MSW incineration bottom ash can be used as cementitious material for the civil engineering applications.

A study was conducted [9] about physical and chemical composition of MSW landfill collected from different locations of Okhla landfill. They found that the moisture content, organic content and concentration of heavy metals in the waste mix are within the limits. So they concluded that MSW landfill material can be used as an earth fill and also as secondary raw material for soil subgrade. Another study focussed on weathering treatment coupled with nano-silica filling for MSW incinerator bottom ash [10]. The work proved that the engineering properties of MSW incinerator bottom ash had improved. So they inferred that the weathering treatment of the material can lead to a reusable construction material. MSW bottom ash had used as admixture for production of ordinary Portland cement concrete [11]. Also, they tested for fine aggregate replacement with MSW bottom ash which did not affect negatively the strength of concrete up to 10% replacement.

MSWL was used for the construction of paving blocks and determined compressive strength and performed leachate analysis [12]. The percentage of heavy metal immobilization in the matrix had decreased with the process of solidification of MSW content with binder. According to another relevant study [13], the landfill is mixed with stabilising binder (cement) in different mixing proportions to find the suitability of the landfill material with respect to compressive strength and heavy metal leaching behaviour analysis. The study revealed that the paving block constructed with cement and fine aggregate ratio 1:2 and waste to fine aggregate ratio 3:7 gave satisfactory compressive strength. They also observed a decreasing trend of release of heavy metals for this optimum mix at 28 days of curing period. The study concluded that solidification and stabilization of waste with binder can effectively reduce the heavy metal ion concentration in waste landfill and the landfill waste can be effectively utilized as construction material after solidification/stabilization techniques.

So in this paper, an experimental investigation is carried out about the reuse of MSWL as a substitute with fine aggregate, with some proportions and tested with mechanical properties and durability parameters.

3. MATERIALS AND EXPERIMENTAL PROGRAM

3.1 Materials

Cement used was Portland Pozzolana Cement and tested with all material properties confirming to [14] and [15]. The physical properties are shown in Table 1. Manufactured sand (M sand), available at the local market, confirming to [16] and [17] have been used as fine aggregates. The physical properties are shown in Table 2 and particle size distribution of M Sand is shown in Fig 1. Coarse aggregates of sizes 20mm and 12.5mm are used with 60:40 ratio respectively. All the material properties have been confirmed with [18] and [19] and shown in Table 3.

3.1.1 Characterisation of MSWL Samples

There were four different aged MSWL samples with 12 years, 10 years, 8 years and 6 years at Vidyaranyapuram landfill, Mysuru, Karnataka, which were dumped separately. All the samples were collected and their physical properties have been found out. Representative samples from all ages have shown in Fig.2. The physical properties of all samples are shown in Table 2 and particle size distribution of the MSWL samples are given in *Fig 1*.

3.1.2 Selection of the sample

By comparing the properties of the samples, it is clear that the most aged sample i.e., the 12-year-old aged sample (MSWL12) is having the highest properties and has been chosen for the experimental program. From the particle size distribution of MSWL12 (*Fig.1*), the percentage of fines passing 150-micron sieve is 34% and hence it was decided to limit its value to 10%. Scanning Electron Microscope (SEM) images of MSWL12 and the chemical composition is shown in *Fig.3.* It is clear from the images and element distribution, the material is in analogy with the fine aggregate using in concrete.

3.2 Mix Proportions

Concrete mix of grade M 30 was designed as per [20] and [21]. M sand was replaced with MSW landfill as 0%, 4%, 5%, 7% and 10%, designated as M0, M4, M5, M7 and M10 respectively as shown in Table 4. Water-cement ratio was maintained as 0.45. Since MSWL sample is expected to absorb more water from the concrete mix, Super Plasticizer namely Conplast SP 430 DIS was added for maintaining the water-cement ratio and workability.

3.3 Slump and Density

Slump cone test was performed according to [15] for finding the workability of the mixes. The density of all the mixes were found out by measuring the weight of the specimen after taking out from curing tank and wiping off the water on the surface of the specimens.

3.4 Compressive strength test

All tests for strength of concrete samples were carried out as per [16]. Concrete was mixed well in a concrete mixer in the laboratory. During casting, vibration table was used to ensure proper compaction. Since the maximum size of the aggregates are 19mm, cube moulds of size 10cm cube moulds were used. A total of 90 cubes were casted to test for compressive strength in the five different proportions. The cubes were stored in a vibration free place for 24 hours from the time of addition of water to the dry ingredients. After this time period, the specimens were marked and removed from the moulds, and submerged in clean and fresh curing water. After 3, 7, 28, 56, 90 and 180 days of curing times, the compressive strength was measured for specimens. The specimens were loaded without shock, continuously at a rate of approximately 140 kg/sqcm/min until the specimen stops to bear load.

3.5 Microstructural analysis of mixes

SEM images from Zeiss Scanning Microscope 15kV were investigated to analyse the microstructure of the concrete specimens. After 28 days of curing, 10mm sized pieces were cut and analysed.

3.6 Splitting tensile strength test

The procedure for the conduction of splitting tensile strength was same as that of the procedure explained in section 3.4, except for cylindrical moulds with 10cm diameter and 20cm height were used to make specimens. Similarly, 90 specimens were casted with same curing conditions in section 3.4.

Table 1. Properties of Cement

Name of Test	**Value**	
Fineness Test	322 m^2/kg	
Consistency Test	33%	
Setting Time Test	Initial setting Time	170 minute
	Final Setting Time	4Hr 40Min
Specific Gravity Test	2.81	
Compressive Strength Test	3 Days	30 N/mm^2
	7 Days	42 N/mm^2
	28 days	56 N/mm^2
	56 Days	58 N/mm^2
Soundness Test	1 mm	

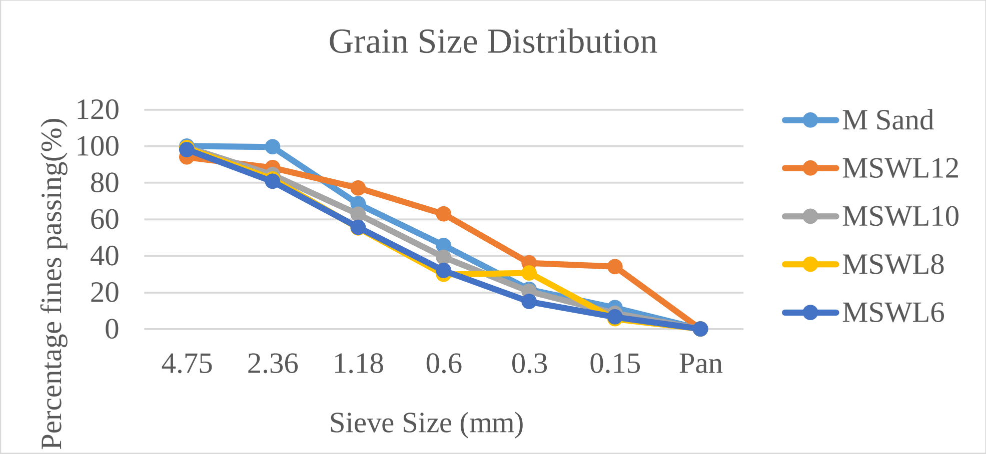

Fig.1. Particle size distribution of M Sand and MSWL Samples

Table 2. Properties of Fine Aggregates

Property	M Sand	MSWL12	MSWL10	MSWL8	MSWL6
Water absorption	2.28%	9.50%	11.35%	13.85%	14.15%
Specific gravity	2.687	2.29	2.115	1.944	1.91
Bulk density (Kg/m^3)	1.687	1.42	1.185	0.815	0.74

Table 3. Properties of Coarse aggregates

Property	20mm Nominal size	12.5mm Nominal size
Water absorption	0.81%	0.63%
Specific gravity	2.72	2.37
Bulk density	1.64	1.522
Aggregate impact value	-	27.13%
Aggregate crushing value	23.30%	24.27%
Los Angeles abrasion value	27.60%	-
Flakiness index	11.65%	0.65%
Elongation index	14.65%	6.05%

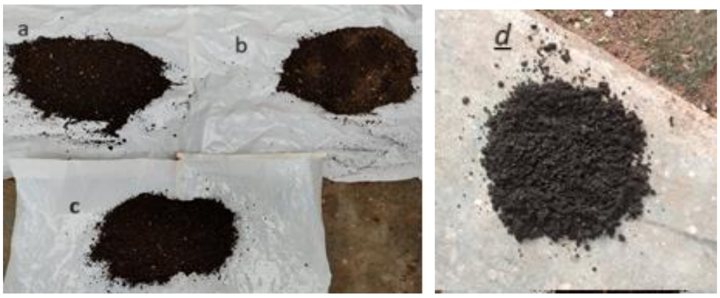

Fig. 2. MSWL Samples a) MSWL6 b) MSWL8 c) MSWL10 and d) MSWL12

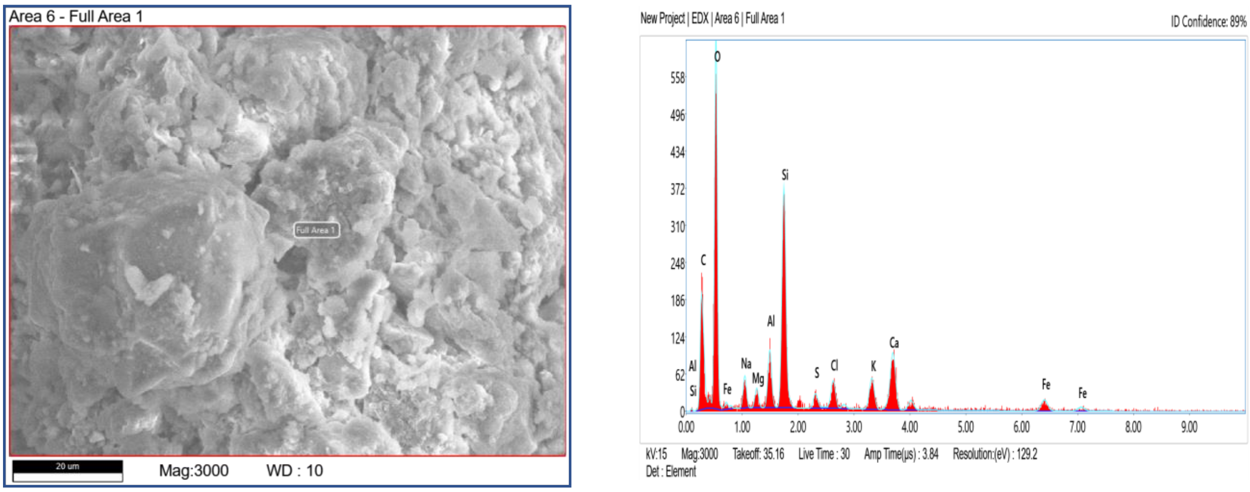

Fig. 3. a) Scanning Electron Microscope (SEM) and b) Energy-Dispersive X-ray microanalysis Test (EDAX) of MSWL 12

Table 4. Concrete Mix Proportion

Mix no.	Cement	M Sand	MSW	Coarse Aggr. 20mm	Coarse Aggr. 12.5mm	Super Plasticizer (%)
M0	1	1.683	0	1.795	1.197	0.4
M4	1	1.616	0.067	1.7955	1.197	0.5
M5	1	1.599	0.084	1.7955	1.197	0.5
M7	1	1.565	0.118	1.7955	1.197	0.6
M10	1	1.515	0.168	1.7955	1.197	0.6

3.7 Flexural strength test

This test was used to calculate the flexural strength of the concrete mixes. Cuboid shaped moulds, with 10cmX10cmX50cm size were used to produce the concrete specimens. 75 specimens were casted with same curing conditions as explained in section 3.4. The loading rate was 180 kg/min and load increased till the specimen fails. The maximum load was used to calculate the flexural strength of concrete as per [21].

3.8 Non-destructive test (Rebound hammer test)

One of the non-destructive tests, rebound hammer test was performed as per [22] as an additional parameter for compressive strength. 15cm square moulds were prepared for each mix in triplicate and tests were done on vertical faces as cast. All the specimens were taken out of curing tank before 24 hours. Nine readings were taken on each face and average value is expressed as rebound number or index.

3.9 Water absorption

Water absorption of the concrete mixes are found out for understanding the variations in water absorbing characteristics of the concrete mix with different percentages of MSWL and as a durability parameter. It was performed by comparing the weights of the specimens before and after immersing in water for curing. The weights of the cubes after 28 days of immersion, after wiping out the extra water at the surface were found out. After that, the cubes were kept in oven for drying for 24 hours and then dry weights were noted. Then the specimens were again kept in water for another 24 hours and then, weights were measured.

3.10 Acid attack

The cube specimens have casted with different percentages of MSWL and cured for 28 days in normal water. After that, the specimens were dipped in 0.5% and 1% sulphuric acid solutions with three specimens for each proportion. After 56 days, 90 days and 180 days of acid curing, the specimens were taken out. Their weight and compressive strength were found out and compared with initial respective values.

The ratio of difference in mass of specimen before and after immersion with acid solution to the initial mass, called Acid Mass Loss Factor (AMLF), after removing the deposits was calculated. Also, the difference in compressive strength with respect to initial strength were calculated. The ratio of change in compressive strength of specimen after immersion period to the initial strength before immersion period, called Acid Strength Loss Factor (ASLF), was calculated.

$$\text{Acid Mass Loss Factor} = \frac{\text{Change in Mass}}{\text{Initial Mass}} \text{ X } 100$$

$$\text{Acid Strength Loss Factor} = \frac{\text{Change in Strength}}{\text{Initial Strength}} \text{ X } 100$$

3.11 Sulphate attack

Here Calcium Sulphate solutions with 5% and 10% solutions were used for finding out the sulphate attack of the mixes. The procedure adopted was same as that of explained in section 3.7.

The ratio of difference in mass of specimens before and after immersion with sulphate solution to the initial mass, called Sulphate Mass Loss Factor (SMLF), after removing the deposits was calculated. Also, the difference in compressive strengths before and after immersion in sulphate solution with respect to initial strength were calculated. The ratio of change in compressive strength of specimen after immersion period to the initial strength before immersion period, called Acid Strength Loss Factor (ASLF), was calculated.

$$\text{Sulphate Mass Loss Factor} = \frac{\text{Change in Mass}}{\text{Initial Mass}} \text{ X } 100$$

$$\text{Sulphate Strength Loss Factor} = \frac{\text{Change in Strength}}{\text{Initial Strength}} \text{ X } 100$$

4. RESULTS AND DISCUSSIONS

4.1 Slump and density

With the increase in the percentage of MSWL in concrete, the slump value had showed a slight decreasing trend from 75 mm to 69 mm (from M0 to M10). Since MSWL has higher water absorption than M sand as depicted in Table 3, the free water in concrete mixes may be reduced with the addition of MSWL in concrete. Hence the slump value, and workability were reduced with increase in percentage of MSWL. However, due to the addition of superplasticizer, this decrease was not quite larger and hence the workability reduction is compensated. The addition of materials with higher water absorption rate will decrease the workability of the concrete is a normal trend [1,23] since the material will absorb the water available in the mix and thus, free water content will get reduced.

The density of concrete was reduced from 2570 kg/m^3 to 2513 kg/m^3 for 10% replacement (M10). The density of concrete mixtures was declined due to the lower specific weight of MSWL compared to M sand. However, it may be noted that the reduction in weight may be negligible since the maximum percentage of density reduction was only about 2.2 (M10), as depicted in *Table 5*.

Table 5. Variation of slump, density and water absorption

Mix	**M0**	**M4**	**M5**	**M7**	**M10**
Slump value (mm)	75	73	72	71	69
% decrease in density	0.0	1.1	1.4	1.6	2.2
Water absorption (%)	2.9	4.1	4.8	5.7	6.6

4.2 Microstructural analysis

The SEM images of normal concrete and MSWL mix are depicted in Figure 4a and 4b. MSWL mix showed a uniform distribution of MSWL particles inside the concrete and hence proved a better compatible replacement for fine aggregate. The gaps inside the MSWL mix are comparatively low with normal concrete which may enhance the strength of concrete. The images proved nearly similar composition and rounded particle shape for both mixes inside. Due to the hydration of cement, C-S-H gel and $Ca(OH)_2$ crystals are formed in both the mixes, with slightly more crystals in MSWL concrete as seen in Fig. 4 a) and b). But rich silica gel, which was formed due to MSWL in the mix may lead to weaker bonds inside the matrix that may cause the reduction in strength. One project [23] had reported that if there are gaps between the aggregate and cement, there will be weaker bond between the ingredients and will result in loss of strength. Additionally, [24] have explained the microstructural analysis of reaction of MSWI bottom ash in concrete. They found that the rich silica gel formed at 28 days of curing had covered the cement particles and weakened the mix, leading to decrease in strength. Also, there occurred delay in hydration process and existence of some unhydrated bottom ash at 28 days of curing.

4.3 Compressive strength

Compressive strength of the cubes is tested at the compression testing machine and all the results are depicted in Fig.4. The results indicated that MSWL may be added to enhance the compressive strength of concrete, but with low percentages only.

Compressive strength values had increased up to 5% replacement (M5) with MSWL compared to conventional mix (M0) and then showed a decreasing trend till M10. The strength increase may be due the filling effect and self-organization of MSWL in concrete mix. The pozzolanic action of MSWL in concrete had helped the mix in increasing strength up to 5% replacement. The maximum rate of increase of compressive strength was 14% for M5 at 3 days and average rate of increase was 6%. The rate of increase was uniform at all different ages of curing times. The increase in compressive strength has been proved with addition of recycled/waste materials in concrete matrix by different studies [25-27].

The rate of increase of strength is more during initial curing ages (3 days of curing). The early strength of the mix may be due to the faster and efficient reaction between surface atoms of MSWL and outer materials. Also the thicker and denser CSH reduced the air voids at early times. But, average rate of decrease was 21% for M10. With increase in MSWL content in the mix reduced the strength of bond between aggregate and cement paste and lower strength of the waste in comparison with the natural aggregate. Additionally more MSWL samples may causes agglomeration due to improper dispersion and hence excess particles act as inert material. The rate of decrease in strength was lower for ages 28 day and more for all other mixes. The falling of compressive strength at higher doses of waste/recycled materials had decreased the value [25, 26, 27].

The maximum compressive strength was for M5 mix in all mixes and in all curing times. So optimum percentage of replacement of MSWL with fine aggregate is 5% with respect to compressive strength.

4.4 Split tensile strength

Fig. 5 clearly indicates the variation of split tensile strength with the mixes at all curing times. The variations were in line with that of compressive strength. The increase in split tensile strength was 15.7% at 3 Days and 6.7% at 180 days for M5. The reason behind the increase in split tensile strength is more or less the same as the reason behind the increase of compressive strength. Furthermore, the formation of the crack during tensile load application was resisted due to the strong Interfacial Transition Zone (ITZ) layer and strong microstructure of the mix. Hence there is a remarkable increase in split tensile strength for the mix. The same trend was observed by earlier studies also with usage of replaced aggregates [1, 5, 26]. Also, like compressive strength, split tensile strength showed high values at early ages of curing.

After M5, the tensile strength also decreased for M7 and M10, which is attributed to the lower physical properties of the MSWL, compared to M Sand and the weaker bond due to more content of MSWL acting as neutral material. For M10, the rate of decrease was 50% at 3 days and 13.4% at 180 days. The presence of MSWL might have weakened ITZ between aggregate and cement, thus reduced the split tensile strength at higher percentages. The replacement with eggshell powder, recycled concrete waste and ceramic and coal waste powder [5,27,28] also marked the same trend of decrease after increasing its content in the concrete mix.

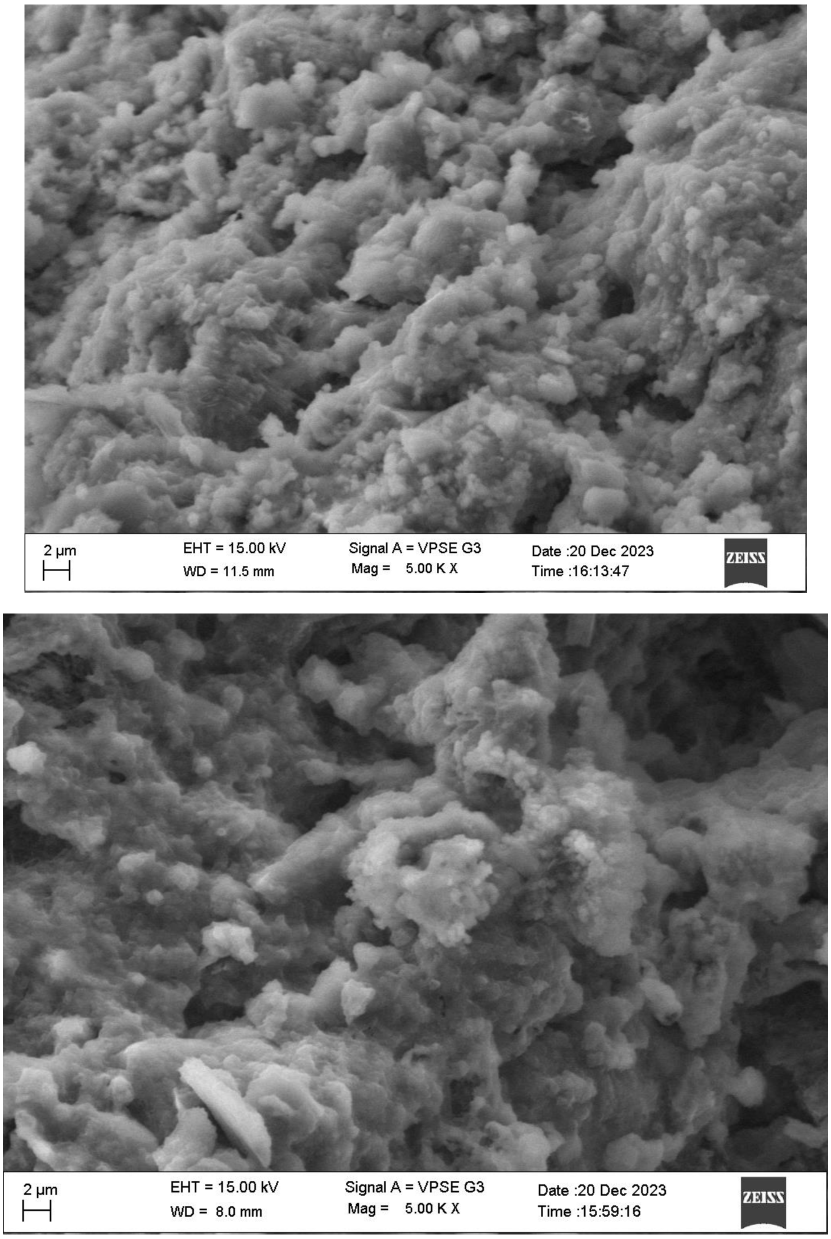

Fig. 4. SEM images of mixes with 5000 magnification of a) Normal concrete b) MSWL concrete

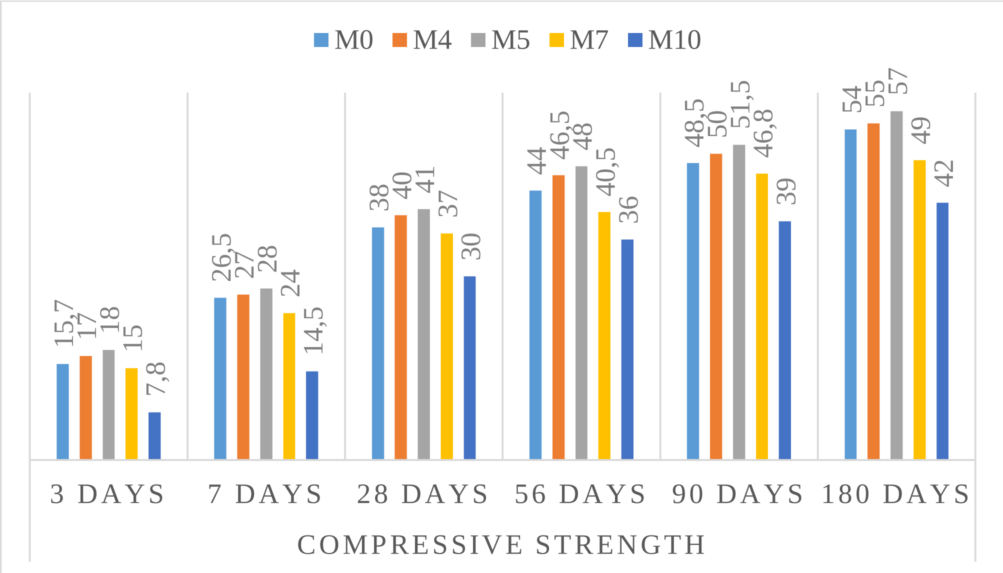

Fig. 4. Compressive strength variation of the mixes

4.5 Flexural strength

The value of flexural strength varied between 5.5 MPa to 7.9 MPa after 90 days of curing which is shown in Fig 6. Compared to compressive and split tensile strengths, flexural strength values had shown an increasing trend till 28 days for M7 (1% rate of increase). For M5, strength was increasing at all ages and the maximum rate of increase was 16.5% at 7 days of curing. The rate of increase was 3.9% at 90 days of curing for M5. The rate of increase is associated with the pozzolanic action of the landfill material and thicker ITZ layer. Moreover, it is also associated with the reduction in air voids and increased stiffness of the cement paste and aggregates by the addition of MSWL. Also the variation of compressive strength and flexural strength will be similar in almost all cases [5, 29, 30].

After M5, flexural strength decreased with more addition of MSWL. The maximum rate of decrease was 32% for M10 at 28 days of curing. This can be attributed to the weaker bond and improper adhesion of the ingredients due to the increased content of MSWL in the mix. Additionally, the reduction can be also associated with poor dispersion of MSWL due to its increased percentage. Additionally, the incorporation of more amount of waste materials will reduce the strength of the mix [5, 25-27, 29, 30]. With all other mixes, MSWL concrete also showed better strength with curing ages. So proper curing also contributed more in all strength parameters.

4.6 Rebound hammer Test

Compressive strength values inferred from rebound hammer index are shown in Table. 6. The variation or trend in compressive strength values is in agreement with compressive strength value measured. However, the difference in values might be justified by the specifications of the test, which describes ±25% accuracy in the prediction of actual strength that may happen with rebound hammer test. However the values gave the correct picture of the trend in strength. When compared the results of compressive strength predicted from calibration curve and measured compressive strength of concrete cylinders [31], they noticed that compressive strength corresponding to rebound index is been underestimated by the actual compressive strength for majority of their test results with the highest variation as 43% lower, which is not at all reliable. In another comparison [32] with the compressive strength results from Ultrasonic Pulse Velocity (UPV) meters and rebound hammer test, they observed a better correlation of the results from rebound hammer test than UPV.

Table 6. Rebound hammer Test results

Mix	Avg Rebound Index	Corresponding compressive strength (N/mm^2)
M0	33.19	29
M4	34.35	30
M5	34.625	33
M7	28.79	28
M10	23.25	20

4.7 Water absorption

The water absorption capacity of the mixes showed an increasing trend from 2.9% to 6.6% (from M0 to M10). MSWL material itself has higher rate of water absorption compared to M sand. Also, the addition of waste material might have increased the free void content of the concrete and thus, weaker bond was created between the cement and MSWL which leads to more water absorption of the mix. Similar increase in water absorption was observed by many studies where fine aggregate is replaced with waste materials [23, 29].

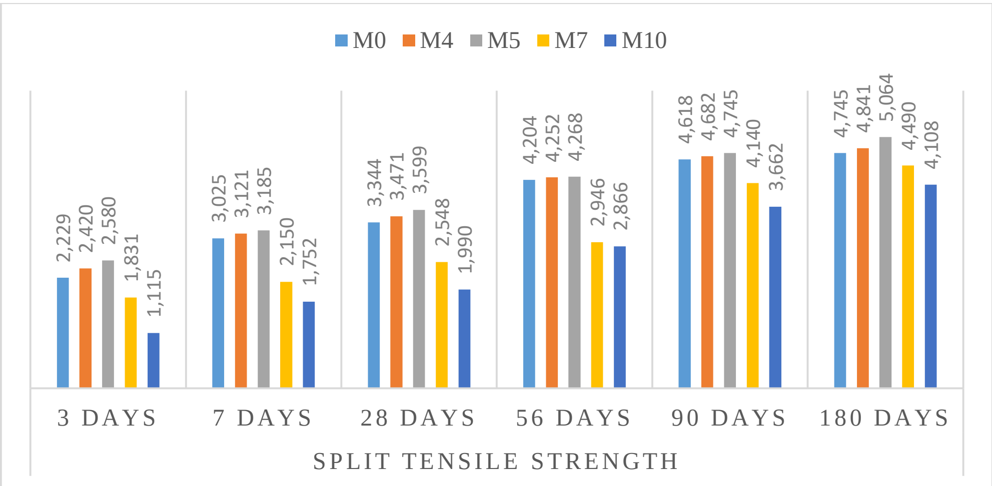

Fig. 5. Split tensile strength variation of the mixes

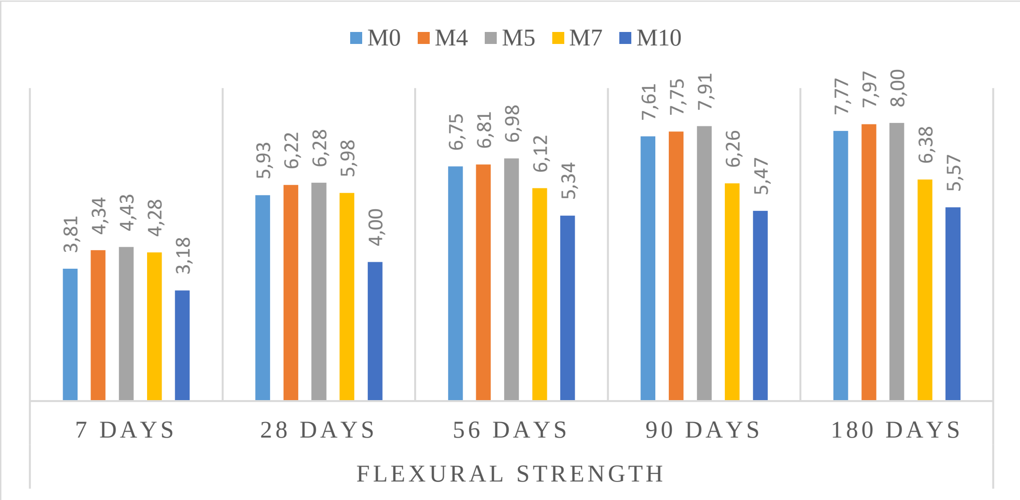

Fig. 6: Flexural strength variation of the mixes

4.8 Acid attack

Durability is inversely proportional to AMLF and ASLF of the concrete. The losses in mass and strength of the specimens exposed to 0.5% & 1% sulphuric acid solution were observed up to 180 days and the results are shown in Fig 7 & 8 respectively. The loss in mass after immersing in acid solution increased with duration of immersion. At 56 days, AMLF was decreased for all the mixes (indicated by negative sign). But for all the other periods, it was increased for all mixes. Also it is found that AMLF is higher in control mix (M0) compared to the mixes M4 and M5. But with M7 mix, weight loss was increased in all immersion periods. It is also observed that the sulphuric acid environment slightly erodes the mortar exposing the coarse aggregate at 180 days as stated by [33]. The mass reduction might be due to the reaction of the acid with cement binder paste which resulted in gypsum formation [29].

Along with AMLF, ASLF also decreased slightly (indicated by negative sign) for 56 days of curing except for M7 mix. All the other mixes showed the increasing trend with all the curing times, except at 90 days of curing with 1% sulphuric acid solution. The cubes were slightly deteriorated with 1% sulphuric acid solutions and hence ASLF has reached up to 57% for M7 at 180 days of curing with 1% sulphuric acid solutions. Immersion in acid solution may led to leaching of calcium products which had produced during hydration of cement paste. This might have reduced the strength of concrete mix [34].

4.9 Sulphate attack

There was an increase in mass for the specimens immersed in 5% calcium sulphate solutions in all ages except for M7 at 56 days. For 10% sulphate immersed specimens, mass decreased at 90 and 180 days except for M7, while it increased for M0 and M4 at 56 days. The incorporation of higher amount of MSWL in the mix decreased the weight of the mix in sulphate solutions. But the loss in mass is less than 1% for all mixes, which is in accordance with the study by [28], which is negligible. Also it was reported that the percentage of mass reduction is not that much in sulphate attack test [30].

Compressive strengths increased for M0, M4 and M5 mixes at 56 and 90 days, while it decreased for M7 for specimens immersed at 5% sulphate solution. Also at 180 days, strength decreased for all the mixes. With 10% sulphate solutions, all the mixes showed higher SSLF at all days of testing. Maximum value of SSLF was 32.65 for M7 at 180 days. The surface of the cubes started deteriorating slightly after 90 days of curing for all mixes. All the results are depicted in Fig. 9 &10. There was no significant difference in deterioration for MSWL mixes as compared to control concrete mix in visual interpretations which proved its resistance against sulphate attack.

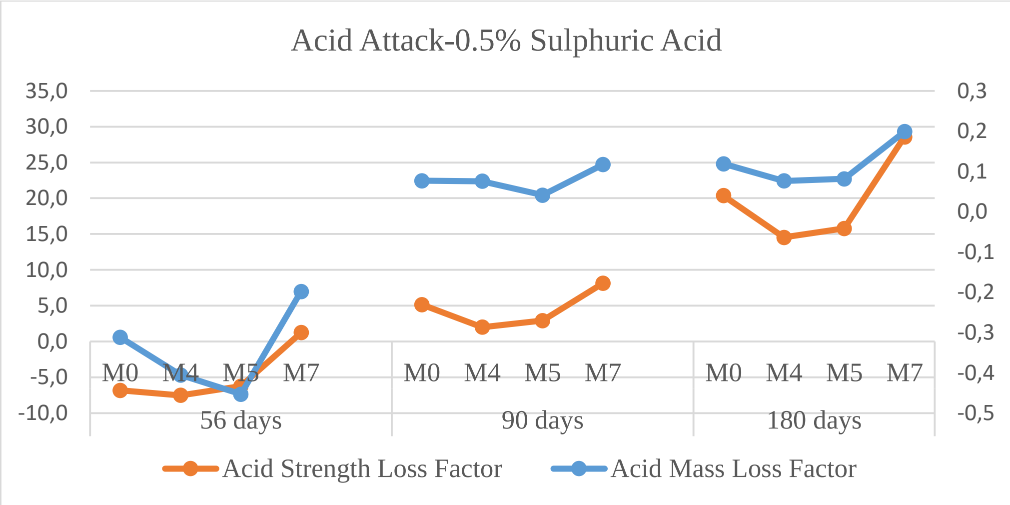

Fig. 7. Variation of Acid Mass Loss Factor and Acid Strength Loss Factor with 0.5% Sulphuric acid

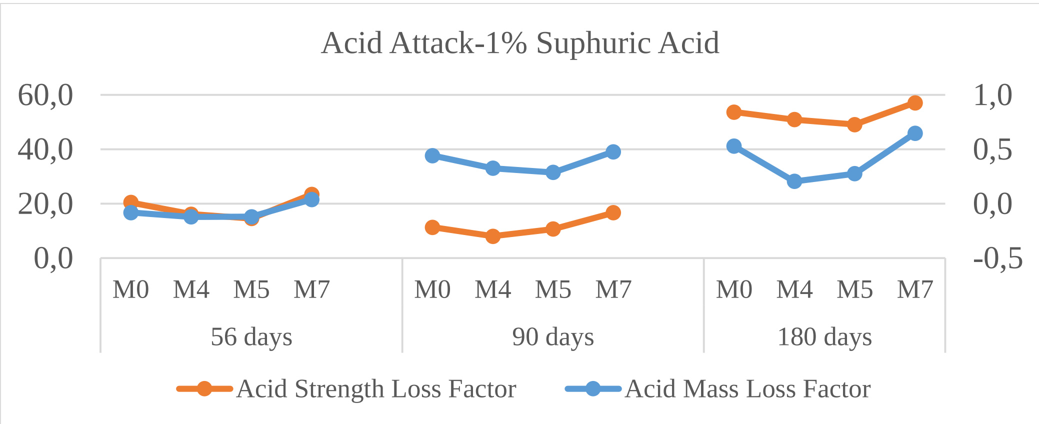

Fig.8. Variation of Acid Mass Loss Factor and Acid Strength Loss Factor with 1% Sulphuric acid

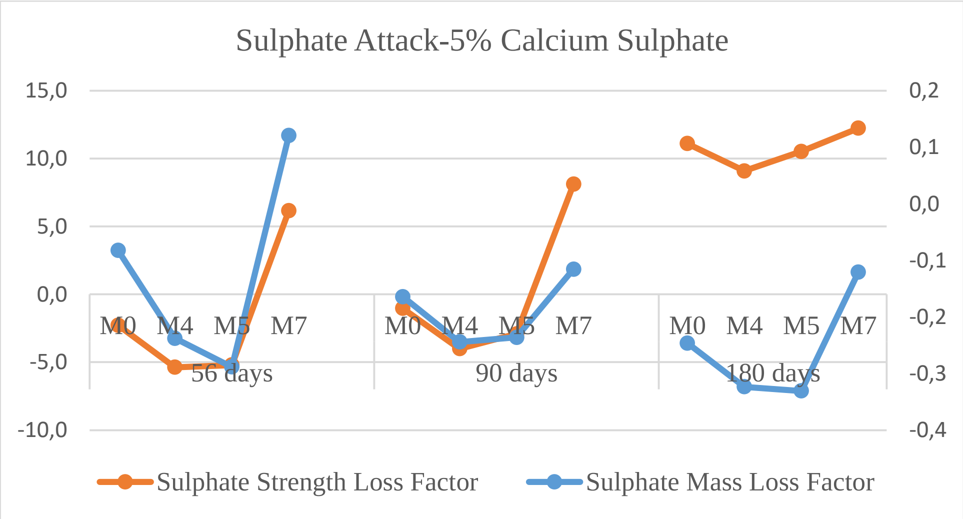

Fig. 9. Variation of Sulphate Mass Loss Factor and Sulphate Strength Loss Factor with 5% Calcium Sulphate solution

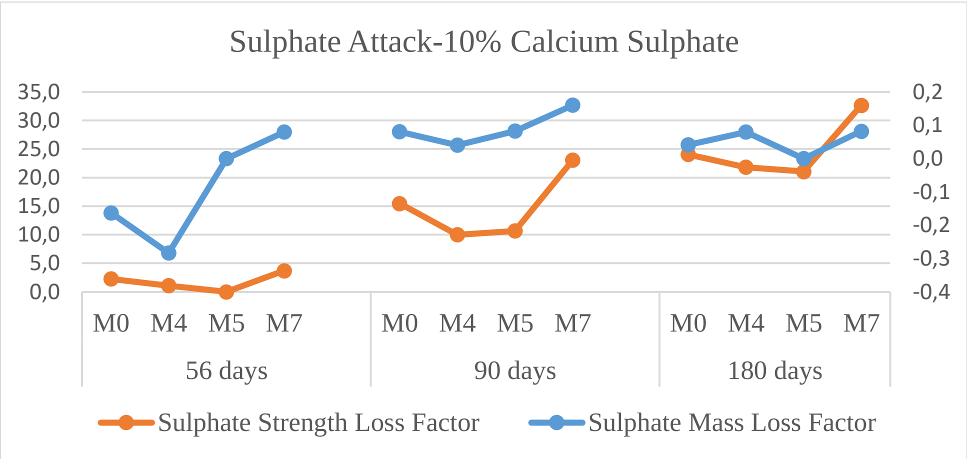

Fig. 10. Variation of Sulphate Mass Loss Factor and Sulphate Strength Loss Factor with 10% Calcium Sulphate solution

5. CONCLUSIONS

This study was conducted to investigate the effect of using MSWL as partial replacement of fine aggregate in concrete with respect to mechanical and durability studies. The following conclusions are drawn from this study.

1. MSWL can be used as a construction material for the production of concrete and the physical properties were good for most aged sample.

2. The density of concrete mixtures had decreased with increase in percent of MSWL in concrete. The water absorption increases with percentage addition of MSWL. It is found that M10 mix showed 28% more water absorption compared to M0.
3. Microstructural images proved the better CSH gel and dense mixture for MSWL concrete compared to normal concrete.
4. Compressive strength had increased till M5 and then showed a decreasing trend. The increase in trend was more precise at early ages. With 5% replacement, MSWL showed more increase in strength.
5. Similar to compressive strength, split tensile strength also showed increase value till M5 and then decreased till M10. Also the increase was more at early ages. For M5, percentage of increase was 7.6% at 28 days compared to M0.
6. Flexural strength also had followed the trend of compressive strength, but with higher prominence. There was 6% increase for M5 mix at 28 days compared to M0. For M7, flexure increased till 28 days, but after 28 days, the value decreased.
7. Rebound hammer test also showed the same trend of variation of strength with different percentage sof MSWL.
8. AMLF and ASLF had increased for all the specimens at all ages with immersion in sulphuric acid solutions. The losses in weight and strength were more for M7 mix compared to M0, M4 and M5. Also, compared to M0, M4 and M5 showed lesser factors which proved the better susceptibility for MSWL mixes with acid.
9. The specimens gave lesser loss factors compared to acid specimens. Weight gain was observed for all specimens, except M7, at 56 days of testing for both sulphate solutions. Strength also increased for M4 and M5 at 56 days with 5% sulphate solution.

It is concluded from the experiments that, MSWL can be reused as a construction material as an economic and sustainable ingredient. MSWL with the most aged sample can be a good replacement for fine aggregate in concrete production. Almost in all tests, M5 mix showed better properties compared to other mixes. By comparing all the test results, 5% replacement of MSWL with fine aggregate is the optimum for the concrete production. The tests lighted to more studies or experiments with MSWL in concrete and also as any other construction material like road embankments, floor tiles, precast panels etc.

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