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Suitability of Laboratory Compaction Procedure for Secondary Materials

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Abstract – The present study evaluates the suitability of the modified proctor test (MPT) using single and multiple batch compactions for two types of secondary materials: reclaimed municipal solid waste (RMSW) and MSW incinerated bottom ash (IBA). In the single batch (SB) technique, the same sample is re-compacted for each successive moisture increment, whereas in the multiple batch (MB) technique, a fresh sample is used for each moisture content. The composition and grain size analysis have substantiated the compaction results of the materials in concern. The maximum dry density values for RMSW were observed to be identical in both SB (1.70-1.74 gm/cc) and MB (1.71-1.75 gm/cc) compaction, indicating no effect of the compaction technique on RMSW. In contrast, SB (1.74-1.80 gm/cc) overestimates the compaction characteristics of IBA compared to MB (1.65-1.69 gm/cc). IBA experiences higher particle crushing in SB compaction, leading to an increase in fines content in each successive compaction phase, resulting in an inaccurate estimation of compaction parameters. Weak constituents like glass and sintered material make the coarse fraction of IBA susceptible to higher particle crushing than RMSW, which was also evident from the aggregate impact test. It is recommended to use the SB compaction for estimating compaction characteristics of RMSW, whereas MB compaction is appropriate for IBA. This study is essential to ensure appropriate field compaction control for using secondary materials in embankments and pavements.

***Keywords*:** RMSW, IBA, Proctor compaction test, Single batch compaction, Multiple batch compaction

1. Introduction

In India, owing to the lack of waste reduction and recycling techniques, two approaches are followed to handle municipal solid waste (MSW) and alleviate the pressure on the dumpsites. The first approach is excavating the legacy dumps [1], referred to as landfill mining. Landfill mining intends to add economic value to excavated waste through recovery, recycling, and reuse. Reclaimed municipal solid waste (RMSW) is the secondary material obtained from mining solid waste from old dump sites. The other approach includes the incineration of MSW in waste-to-energy facilities [2] at high temperatures (850-1000^{o}C), which generates electricity and reduces the waste quantity by 75-80% (by weight). Incinerated bottom ash (IBA) is the primary residue obtained from the plant. Currently, neither RMSW nor IBA have any off-site applications in India [3].

Limited availability of natural materials and stringent regulations governing their use, the emphasis has shifted to use secondary materials for civil engineering applications such as fills and pavements, thereby promoting sustainable development [4]. It would be advantageous if these secondary materials (RMSW and IBA) could be utilized in bulk quantities so that a lesser quantity of waste is left for landfilling.

The literature suggests that RMSW can be reused in off-site field applications after initial processing and treatment, such as washing, thermal treatment, solidification, and stabilization, [5-7]. Isolated reuse of IBA is found to be satisfactory for fill and road applications [8-12]. However, these materials have region-specific characteristics that vary based on MSW heterogeneity, pre-processing of waste, and incineration technology (in the case of IBA). Consequently, the suitability of these materials for field applications depends considerably on their geotechnical and geoenvironmental characteristics. One such essential requirement is determining accurate compaction characteristics to ensure adequate density in the field. Inadequate compaction may result in reduced stiffness, rutting, and settlement issues.

R.R. Proctor introduced the conventional compaction test to determine field compaction parameters, maximum dry density (MDD), and optimum moisture content (OMC) for natural aggregates using an impact rammer. Though improved laboratory compaction methods (vibratory and gyratory compactions) replicate the field compaction [13] better than proctor test but still the proctor compaction results are used worldwide for compaction of granular materials in pavements [14-15]. MoRTH (2013) recommends heavy compaction for road and embankment applications for which a modified proctor test (MPT) is suitable [15]. The relevance of the standard proctor test (SPT) in the case of secondary material is debatable due to the high energy compaction been undertaken in the field. Hence, the present study focuses only on MPT.

As per the codal provision [16], the conventional proctor test for natural aggregates uses a single batch (SB) technique, in which the same material is used and re-compacted for different moisture contents. This technique requires less material and time to complete the test. In another case, a fresh sample is taken for each increment of moisture content, referred to as the multiple batch (MB) technique. It is usually believed that both techniques might yield identical results; hence, the single batch technique is a common practice to save material and time. However, there is no substantial experience of such techniques for secondary materials. Therefore, the present study intends to evaluate the suitability of conventional laboratory compaction procedures for the concerned secondary materials (RMSW and IBA). The relevance of single and multiple-batch techniques has been studied, and the appropriate test method for secondary material has been suggested. The study will facilitate end users during field applications of these materials.

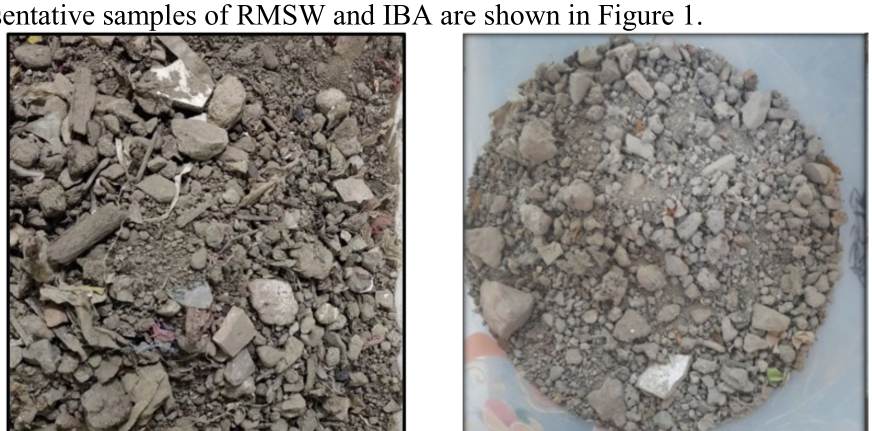
2. Material and Methodology

2.1. Material Collection

In the current study, RMSW samples were collected from a legacy dumpsite in Delhi that has been in operation since 1996; the site is situated at 28.50ºN, 77.28ºE. This waste dump contains about six million tons of legacy waste. The excavated material was observed to be 10-20 years old. This location is equipped with 30 mm screen trommels to segregate the mixed MSW into construction and demolition waste (CDW), refused derived fuel (RDF), and minus 30 mm fractions. During sampling, six trommels were operational at the studied site, and representative RMSW samples were collected from three trommels located in three different directions.

IBA samples were obtained from an incineration facility in Delhi operating using moving grate technology. The plant has been operational since 2017 with a daily power generation capacity of 24 MW. The plant receives around 2000 tons of MSW daily, and after processing, about 1200 tons of waste is fed for incineration, and subsequently, around 320-340 tons of IBA is generated daily. The residues were stockpiled at the plant for 10 days, and approximately 4-5 tons of the IBA samples were collected. The collected material was observed to have a moisture content of 12-18%. The samples were therefore spread in thin layers for air-drying, followed by sieving through a 30 mm screen to obtain representative samples.

RMSW and IBA samples (minus 30 mm) were collected in clean airtight containers and were immediately transferred to the laboratory. Representative samples of RMSW and IBA are shown in Figure 1.



(a) (b)

Fig. 1: Representative sample of a) RMSW, b) IBA

2.2. Experimental Study

Approximately 200-250 kg representative RMSW and IBA samples were obtained using coning and quartering, and compositional analyses were performed following ASTM D5231-16. Wet sieve analyses were carried out to determine the grain size distribution of both materials using IS: 2720 Part IV-85. An aggregate impact test (IS: 2386 Part IV-63) was also performed on the coarser fraction (4.75-30 mm) to assess the toughness and the possibility of particle breakdown during impact compaction.

The conventional laboratory approach for determining the maximum dry density and optimum moisture content was followed as per IS: 2720 Part VIII-83 for the modified proctor compaction test [16]. The concerned material has a maximum particle size of 30 mm, which is permitted as per Indian standards. The standard procedure for MPT follows single batching, where the same specimen is re-compacted for each increment of moisture content. This method was compared with an alternate procedure of multiple batching, where a new specimen was used for each increment of moisture content. After the compaction test, wet sieve analyses were performed on the specimen to evaluate the effect of crushing caused by impact in single and multiple batch compactions. All the tests were performed in triplicates to ensure the quality of the study.

3. Results and Discussions

3.1 Compositional Analysis

The constituents of RMSW and IBA were manually sorted into five broad categories, namely soil-like material (<4.75 mm), construction and demolition (C&D) waste, non-combustibles, combustibles, and sintered material. C&D waste includes aggregates, brickbats, demolished concrete fragments, and ceramics; non-combustibles include metals and glass; combustibles include plastic, wood, cloths, rags, and paper. Sintered materials are porous quenched materials formed by the fusion of ash during incineration at high temperatures [17-18]. Both materials have approximately 65-70% of soil-like material, and the coarse fraction constitutes the remaining categories, as shown in Table 1. The higher percentage of sintered material and glass in IBA compared to RMSW affects material characteristics, which was also evident from the impact test and MPT.

Table 1: Compositional Analysis of RMSW and IBA

Particle Size	Category	% by dry weight	
		RMSW	IBA
Fine fraction (< 4.75 mm)	Soil-like material	69 ± 5	64.5 ± 3
Coarse fraction (4.75-30 mm)	C&D waste	31 ± 8	19.6 ± 2.1
	Non-Combustibles	1.05 ± 0.25	3.1 ± 0.12
	Combustibles	1.55 ± 0.05	1.1 ± 0.08
	Sintered Material	NA	11.7 ± 1.3

3.2 Proctor Compaction Test

Single and multiple batching proctor compaction tests were performed on RMSW and IBA to ascertain the efficacy of conventional MPT on these secondary materials. Each compaction test was performed at 7 different moisture content ranging from 2% to 18%. The results of compaction test are presented in Figure 2, the tests were performed in triplicates (SB1 to SB3 and MB1 to MB3), and average values (SB average and MB average) were calculated. It has been observed that the compaction characteristics for RMSW estimated from the SB (1.72 gm/cc, 14.9%) are nearly identical to MB (1.73 gm/cc, 14.2%) and have no effect of compaction techniques. In contrast, the MDD and OMC values for IBA in MB (1.67 gm/cc, 13%) are lower than in SB (1.76 gm/cc, 14%). Consequently, laboratory results of SB compaction overestimate compaction characteristics of IBA, which may be difficult to obtain in the field. Field compaction control requires an MDD and OMC of more than 95% obtained from the laboratory values [15]. This control may fail due to possibility of lower density achieved in the field, and hence, IBA might not find its suitability in embankments and road applications.

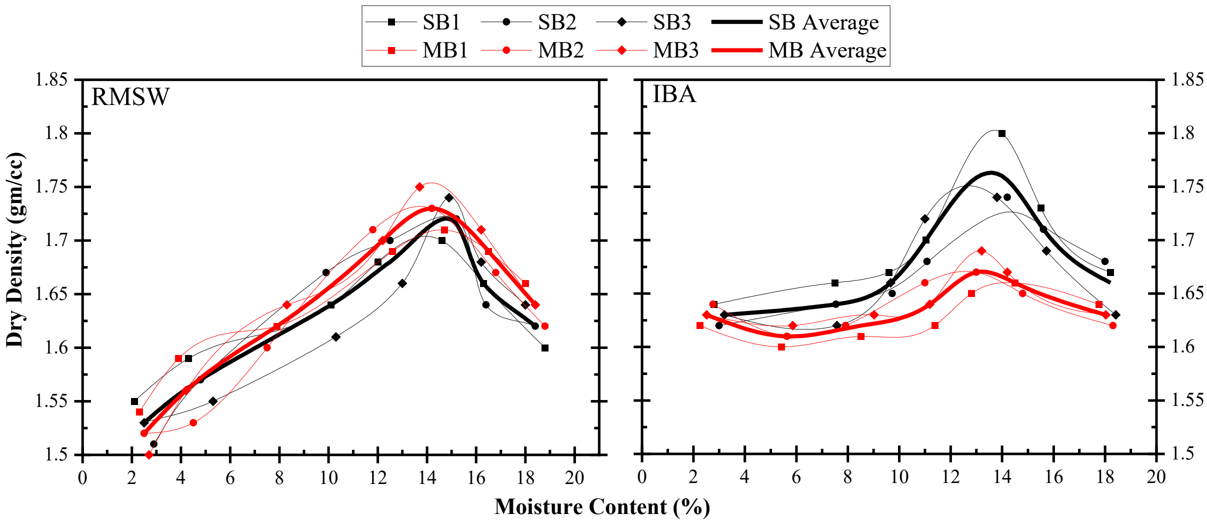


Fig. 2: Single and multiple batch compaction curves for RMSW and IBA

The difference in the behavior of these two secondary materials can be attributed to changes in fines (< 75 µm) before and after the compaction test. Figure 3 shows the average grain size distribution (GSD) curves based on the results of three sets of tests for RMSW and IBA before and after compaction. In the case of MB compaction, GSD curves are plotted corresponding to three moisture contents: one dry of optimum (MB_d), at OMC (MB_o), and one wet of optimum (MB_w).

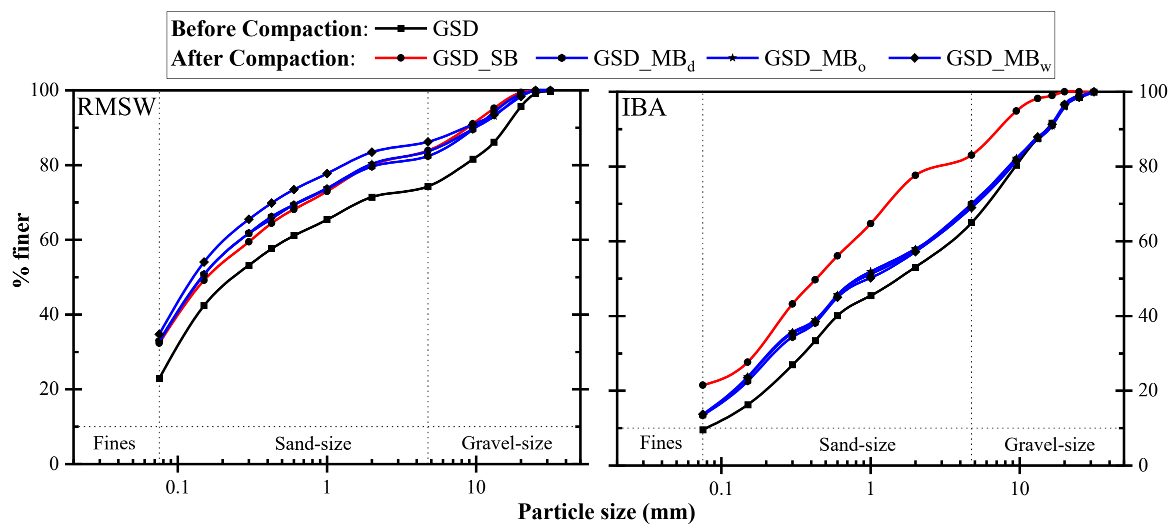


Fig. 3: GSD curves for RMSW and IBA before and after compaction

Significant fines of about 22-25% have been observed in RMSW before compaction, whereas a minor increment in fines was observed after SB and MB compaction. Also, the fines generated in RMSW in SB and MB tests are almost similar. On the contrary, IBA has initial fines of 9-11% before compaction and increases to 20-22% after SB compaction. This suggests that IBA undergoes particle crushing in subsequent stages of SB compaction. The crushing behavior of IBA compared to RMSW was also evaluated using an aggregate impact test. After MB compaction in IBA, fines increase to 12-14%, which is insignificant compared to SB compaction. Thus, it can be inferred that fines play an essential role in the compaction characteristics of secondary materials. Izquierdo et al. (2011) have also suggested that increased fines in IBA led to an overestimation of MDD and OMC in SB compaction [19].

3.3 Aggregate Impact Test

Even though the IS specification [20] requires testing on the material of size 10-12.5 mm, the testing was performed for different gradations (30-25 mm, 25-20 mm, 20-12.5 mm, 12.5-10 mm, and 10-4.75 mm) to capture the effect of particle size and ascertain the overall behavior of the coarse fractions under impact loading. The impact values of RMSW and IBA are presented in Table 2. The presence of sintered material and a higher percentage of glass (reflected in a high percentage of non-combustibles) in IBA than in RMSW make it friable when subjected to impact loading and hence, is susceptible to more particle breakdown [19]. Thus, the aggregate impact test results have also substantiated that the coarser fraction of IBA underwent more particle crushing than RMSW when subjected to impact loading.

Table 2: Aggregate Impact Values of RMSW and IBA

Particle Size (mm)	Impact value (%)	
	RMSW	IBA
4.75-10	43.8 ± 2.6	54.5 ± 2.4
10-12.5	39.8 ± 2.1	53.1 ± 2.1
12.5-20	35.4 ± 2.7	54.8 ± 1.2
20-25	36.6 ± 2.0	51.1 ± 0.3
25-30	40.2 ± 2.3	52.8 ± 1.3

4. Conclusions

Determining accurate compaction characteristics of secondary material is one of the essential requirements to ensure field compaction control in embankments and pavements. The study assesses the suitability of conventional laboratory proctor compaction for secondary materials (RMSW and IBA). The research work was supplemented by compositional analysis, grain size distribution, and aggregate impact tests. Based on the outcomes obtained from the experimental study, the following conclusions can be drawn:

- An increase in fines content during impact compaction and results of aggregate impact tests suggest that IBA is more susceptible to particle crushing than RMSW, affecting compaction characteristics.
- Single and Multiple batch proctor compaction have produced comparable compaction characteristics for RMSW. Therefore, using single batch results of RMSW for compaction in the field is recommended.
- In single batching, re-compaction of the same material is easy, time-efficient, and requires less material. Nonetheless, the results obtained from this method may not be achievable during field compaction control owing to higher particle crushing during impact compaction of some secondary materials.
- In the case of IBA, single batch compaction overestimates MDD and OMC. Thus, multiple batch values are recommended for field compaction of IBA.

Acknowledgments

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