Physical and Swell Behaviour of Sand-Bentonite and Marble Dust-Bentonite Mixes

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Abstract. Numerous researches have been carried out on bentonite amended with soils (commonly sand) to form barriers material for waste disposal projects such as landfill, cores of zoned earth dams and radioactive waste repository systems. However, the development of sustainable geo-materials is still a greater concern for geotechnical engineer. Bulk utilization of marble dust, produced in the Rajasthan, is a serious concern for safe environment. In the present study, an attempt has been made to modify the behaviour of marble dust with bentonite to develop a novel liner material for landfill system. Further, the behaviour of marble dust amended with bentonite has been compared with sand-bentonite mixture which is known to be used as a liner material. Atterberg's limits, free swell index (FSI) and compaction characteristics (i.e. optimum water content and maximum dry density) of various proportion of both sand-bentonite and marble dust-bentonite mixtures (0:100 to 100:0) were determined. It is observed that MDD and OWC of sand reduce and, increase with an increase in its substitution with bentonite, respectively. The similar tendencies have been observed for marble dust-bentonite mixes. Further, the FSI of sand and marble dust is also observed to be increased drastically with its substitution with bentonite. The physicochemical examinations (pH and Electrical Conductivity (EC)) of entire mixes have been performed to elucidate the mechanism.

Keywords: Bentonite, Liner, Marble dust, Sand, Swell.

1 Introduction

The generation of hazardous wastes gradually due to rapid advancement in technology and population has led to create many problems such as waste management [1]. Until the middle of this century, all unwanted waste were being used to discard in open un-engineered dumps or, to bury it in land with very little attention given to their environmental impact [2]. The natural depressions like creeks, low lying areas and flood plains were used to dump the waste. No attempt was made, neither, to segregate waste nor, was consideration given to leachate control. Groundwater contamination due to improper past waste disposal practices, leaking underground storage tanks and accidental spills has been a growing concern on a global scale [3]. One of the main objectives in the design of a landfill site should be the proper management of polluted water and leachate migration, therefore mitigating the risk of health and environmental damage.

Conventionally, compacted liner materials were constructed by using soils having rich in clay mineral due to their low hydraulic conductivity (i. e. less than 10^{-7} cm/s) [4]. Bentonite is also the most suitable material which can be used as a liner material in an engineered landfill. Bentonite is mainly composed of SiO_2 (61.03%) and Al_2O_3 (14.59%) [5]. Bentonite has a high-water absorption capacity causing it to expand and swell due to the presence of montmorillonite minerals. To overcome the problem associated with low shear strength and swell-shrink in clay and bentonite, granular material such as sand were used to improve their properties [1, 6]. However, the major challenges with conventional liner (bentonite, bentonite-clay, bentonite-sand etc.) include; i) damage during the placement of the wastes, ii) alteration in the properties of liner materials, iii) reduction in capacity of primary leachate drainage layer over time because of biologically induced clogging, and iv) poor sustainability and economical. Further, sand seems like an infinite resource-especially when one imagines endless beaches and deserts-but the granular material is one of the most-consumed resources on the planet, and it could be running out. The problem of conventional liner and replacement of sand can be resolved by innovating a suitable liner material.

In developing countries, marble are still one of the most popular and decorative construction materials. India is the largest producer of waste marble dust. Around 95% of the total marble in the country are being produced only in Rajasthan state, India and hence, can be considered as the World’s largest marble production [7]. Among them about 70% of marble waste generated from 4000 marble mines in Rajasthan, India possesses a major environmental concern and local ecosystems due to its unscientific disposal [7, 8]. Therefore, usage of the marble dust in various construction industry would help to protect the environment. Marble dust can be used as a filler materials to fill the voids present due to its fineness and to enhance the property of expansive clays [9]. Further, marble powder has been used as an additive for brick manufacturing, concrete production, and highway construction [10, 11]. Some research has been done on the application of marble powder to improve the properties of clay soil [9, 7]. Marble dust has large percentage of CaO (66.60%) and MgO (22.13%); and sand has large percentage of SiO_2 (78.67%) and Al_2O_3 (12.20%) [12]. Further, the coarser particles and significant shear strength of marble dust improve the workability, plasticity and strength soils, particularly for cohesive soils [11]. However, attempt has not been made to study the potential of marble dust to be used as a liner material in combination with bentonite and is prime motive of present work.

The present work is focused to develop the novel liner material by capturing the advantageous properties of marble dust in improving the behaviour of bentonite. The detailed physical properties (Atterberg’s limits and swell index), physicochemical (pH and EC) and compaction characteristics of marble dust-bentonite mixes has been studied to examine its suitability in developing linear material. Further, comparative study of marble dust-bentonite mixes has been done by determining the properties of sand-bentonite mixes to understand the potential of marble dust to be used as a liner material in replacement of sand.

2 Materials Used and Methodologies Followed

2.1 Materials Used

The geotechnical properties of bentonite, sand and marble dust are presented in Table 1. Micro-analyses (XRD, SEM and EDAX) of parent materials are shown in Fig. 1 (A-F) and Table 2.

Bentonite (B)
The bentonite used for the study was collected from Bikaner District, Rajasthan, India. The geotechnical properties of bentonite are presented in Table 1. Particle size analysis of bentonite shows the presence of sand sized particle (4.75 – 0.075 mm) of 8.00%, silt sized particle (0.075 – 0.002 mm) of 15.00% and clay sized particle (<0.002mm) of 77.00%. Bentonite has liquid limit of 185% and specific gravity of 2.55. Further, Free Swell Index (FSI) and Modified Free Swell Index MFSI of bentonite are observed to be 490% and 13.04 ml/gm, respectively.

The XRD analysis of bentonite [Fig. 1(A)] shows the presence of montmorillonite, kaolinite and quartz as predominant minerals. The microscopic image of bentonite [Fig. 1(B)] illustrates the rounded particle shape and more symmetrical particle size distribution, with smaller average grain sizes. The elemental analysis of bentonite by energy dispersive X-ray spectrometer (EDAX) confirms the presence of oxygen, carbon and silica with large percentage and potassium, titanium and chlorine in small percentage (Table 2).

Soil
The soil used for the study was collected from Manipal University Jaipur, Rajasthan, India. The soil used for the present study is from the depth of 1-1.5m below the ground surface. The material passing from IS 425 micron sieve is used for all experimental purpose. The geotechnical properties of soil is presented in Table 1. The particle size analysis of soil confirms the presence of predominated amount of sand sized particles (98.50%) and hence, it is represented as a Sand (S) in the present study. The sand has a maximum dry density (ρ_{max}) and optimum water content (OWC) of 1.58g/cc and 14.44%, respectively.

Soil predominated with sand sized particles is predominated with rutile, quartz, feldspar & mica (Fig. 1C). The SEM image (Fig. 1D) and EDAX examination (Table 2) of sand confirm the irregular shape of particles and presence of silica as a key element, respectively.

Marble Dust (MD)

The marble dust used for the study was collected from Kishangarh, Ajmer District, Rajasthan, India. The particle size analysis shows the predominated amount of sand sized particle of 96.50%. The specific gravity of marble dust is obtained to be 2.74. The maximum dry density and OWC of MD are observed to be 1.87g/cc and 15.03%, respectively.

Mineralogical analysis of MD (Fig. 1E) confirms the presence of dolomite and calcite as predominated minerals having minor component of quartz. The SEM image of marble dust [Fig. 1F] enunciates the irregular and flaky shape of particles. The chemical composition (Table 2) analysis of marble dust shows the presence of calcium (8.77%) and magnesium (8.40%) as a predominant element.

Table 1. Geotechnical Properties of Parent Materials.

Property	**B**	**MD**	**S**	**Methodologies followed**
Sand (4.75 – 0.075 mm), %	8.00	96.50	98.50	IS-2720 (Part-4) [13]
Silt (0.075 – 0.002 mm), %	15.00	3.50	1.50	
Clay (<0.002mm), %	77.00	-	-	
Specific Gravity	2.55	2.74	2.63	IS-2720 (Part 3) [14]
Liquid limit, %	185.00	17.60	30.76	IS-2720 (Part 5) [15]
Plastic limit, %	67.33	-	-	IS-2720 (Part 5) [15]
Plasticity index, %	117.67	-	-	
Shrinkage Limit, %	8.05	-	-	IS-2720 Part 6 [16]
Differential FSI, %	490.00	-	-	IS 2720 Part 40 [17]
Modified FSI, (ml/gm)	13.04	-	-	Sivapullaiah et al. [18]
Optimum Water Content, %	45.76	15.03	14.44	Sridharan and Sivapullaiah [19]
Max. Dry Density, g/cc	1.12	1.87	1.58	
pH Value	7.97	8.20	8.31	IS 2720 Part 26 [20]
EC, mS/cm	0.28	0.11	0.14	

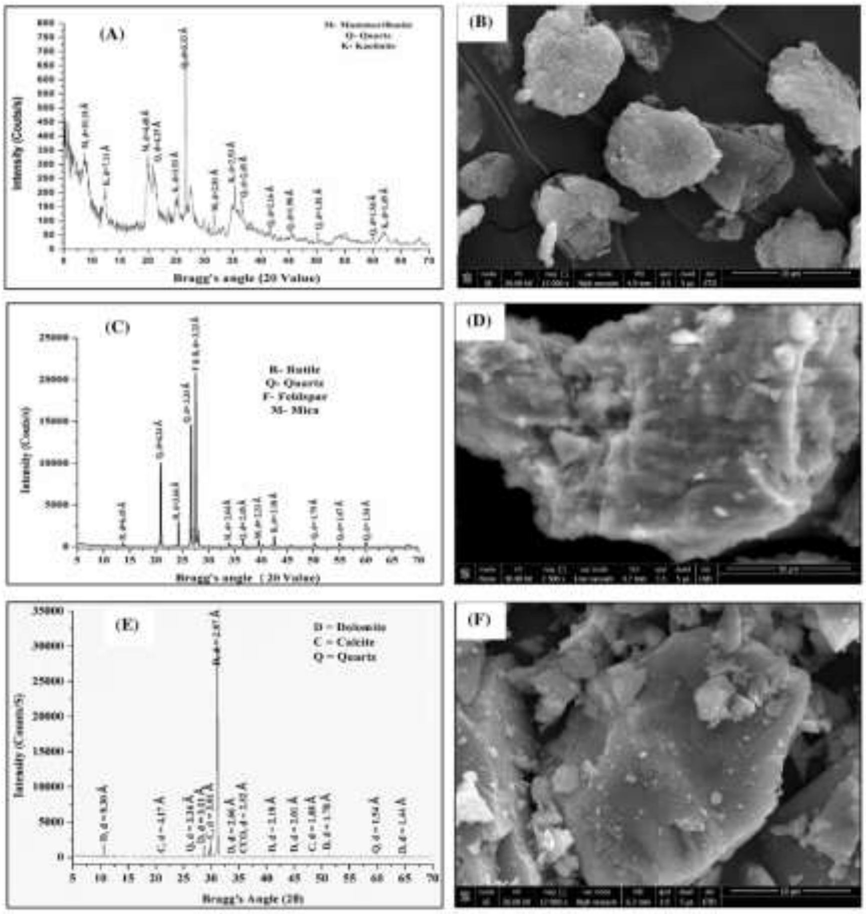

Fig. 1. XRD analyses and SEM images of (A) and (B) Bentonite; (C) and (D) Sand and (E) and (F) Marble dust.

Table 2. Chemical Composition of bentonite, sand and marble dust.

Element	Atomic %		
	Bentonite	Sand	Marble Dust
O	56.85	71.28	60.52
Si	12.95	21.24	0.51
Al	8.42	3.99	-
Fe	2.94	1.01	-
K	0.25	0.72	-
Mg	1.42	0.81	8.40
Ca	-	0.31	8.77
Na	2.46	0.50	-
Ti	0.54	0.15	-
C	13.83	0.00	21.81
Total	100.00	100.00	100.00

2.2 Methodologies Followed

The methodologies followed to determine the geotechnical properties of parent materials are listed in Table 1. The pH tests are conducted according to IS 2720 Part 26 1987. The instrument was calibrated with standard buffer solution of pH 4.0, 7.0 and 9.0 prior determining pH value of all the samples. The same samples are used to measure the electrical conductivity.

The X-ray diffraction (XRD) of materials is performed by using graphite monochromator and Cu-Kα radiation. The scanning angle (also known as Bragg's angle) is kept in the range of 3° to 90°. The X'pert highscore software is used to analysis and to identify the presence of various minerals as per sample data file of Joint Committee on Powder Diffraction Standards (JCPDS) [21]. Scanning Electron Microscope (SEM) coupled with Energy Dispersive X–ray Spectroscopy (EDAX) is performed to examine microstructural and chemical composition of materials used. The sample was coated with 100 Å thin layer of gold palladium for 38 second using a sputter coater, polaron E5100 at 10^{-3} Torr Vacuum. The same samples are used for elemental analysis by EDAX.

The sample prepared to determine the physical properties of B-S and B-MD mixes are based on their dry weight. Varying percentage of bentonite up to 100% is substituted by dry weight of S and MD to prepare the mixes. The dry mixes are done prior to wet mixing with water to determine the properties.

3 Results and Discussion

3.1 pH and Electrical Conductivity (EC) of Bentonite with Marble Dust & Sand

The physicochemical properties of marble dust and sand mixed with bentonite are measured in terms of pH and electrical conductivity and are shown in Fig. 2.

It is observed that the pH of soil amended up to 20% bentonite content increases and reduces thereafter up to 95%. The availability of calcite increases the concentration of salt cations in the soil solution which increases the ionic strength, resulting to the change in pH of soil amended up to 20% bentonite [22].Whereas, the reduction in the buffering capacity of soil due to decreasing percentage of calcite with addition of bentonite causes a reduction in pH after 20%. Similar result is shown for B-S mixes. Further, electrical conductivity of soil and marble dust also increases with increase of bentonite percentage. Electrical conduction in soil occurs due to the presence of moisture and surface charge. Soil-water interaction depends on the surface charge of clayey soil [23]. Na^+ and Ca^{++} become higher with increase in amount of bentonite [24]. Because of increase of charges in the solution with increase of bentonite electrical conductivity increases. Further, bentonite has higher electrical conductivity value compared to sand and marble dust (Table 1). However, it is interesting to note that pH and EC of both sand and marble dust follow similar trends with increase in bentonite percentage.

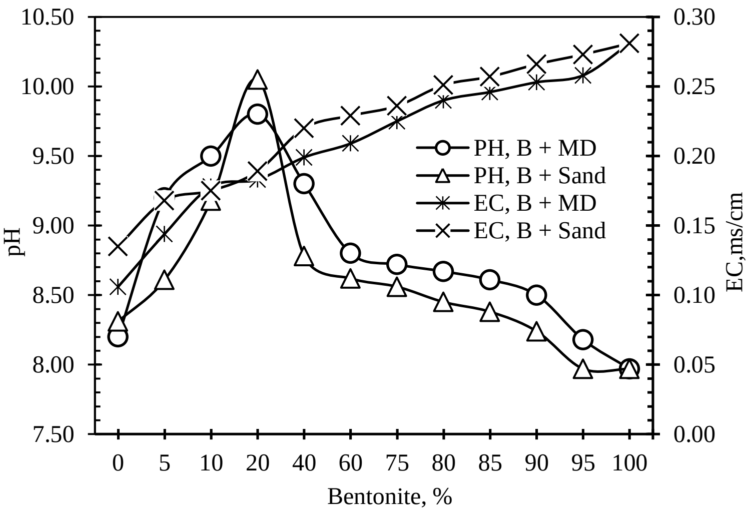

Fig. 2. pH and Electrical Conductivity of Marble Dust-Bentonite and Sand-Bentonite Mixes

3.2 Plasticity Characteristics of Bentonite with Marble dust and Sand

Influence of bentonite on Atterberg's limit (liquid limit, plastic limit and plasticity index) of marble dust & sand is shown in Fig. 3 & 4, respectively. It is observed that liquid limit increases with increasing in bentonite content up to 95%, i.e. from 30.76% to 180% and 17.6% to 164% for B-S and B-MD mixes respectively. Similar trend is obtained for plasticity indexes which increase from 30.76% to 115.77% and 17.60% to 97.55% for B-S and B-MD mixes up to the addition of 95% of bentonite, respectively. It is observed from Fig. 3 and Fig. 4 that plastic limit increases to 66.44% and 64.22% up to addition of 95% bentonite to MD and S mixes, respectively. Hence, the plasticity index of S and MD increases with addition of bentonite. These increment are attributed to (i) surface charge of bentonite, (ii) thinner particle size of bentonite, (iii) greater amount of water absorbed and (iv) increase in the DDL (diffuse double layer) thickness [6].

It was noticed from the Fig. 5 that shrinkage limit increases to 17.454% and 10.611% with increasing amount of bentonite up to 40% for B-S and B-MD mixes, respectively. Further increment in bentonite content up to 95% results in reduction of shrinkage limit from 17.454% to 10.835% and 10.611% to 8.053% for B-S and B-MD mixes, respectively. The variation in shrinkage limit is attributed to change in the fabric of the sand and MD with addition of bentonite [25]. It can be summarized that bentonite in combination of marble dust possesses similar plasticity behaviour than that of bentonite-sand mixes.

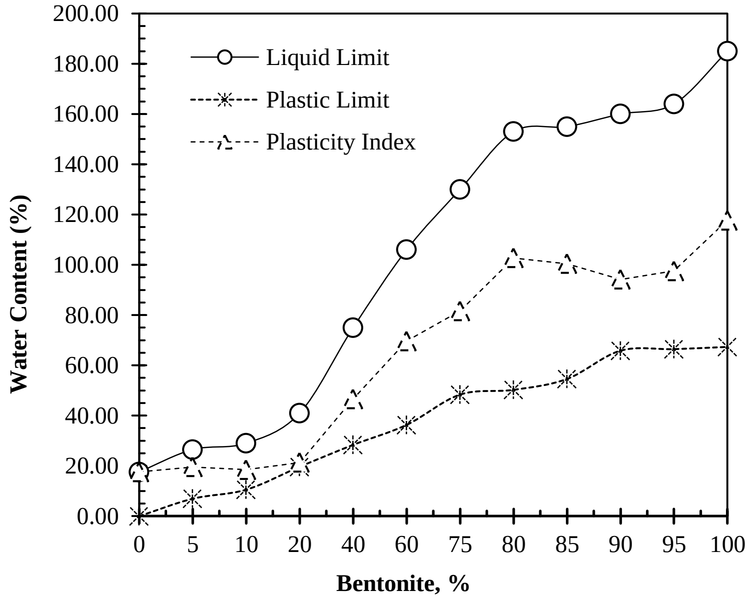

Fig. 3. Variation on liquid limit, plastic limit and plasticity index of marble dust with addition to bentonite

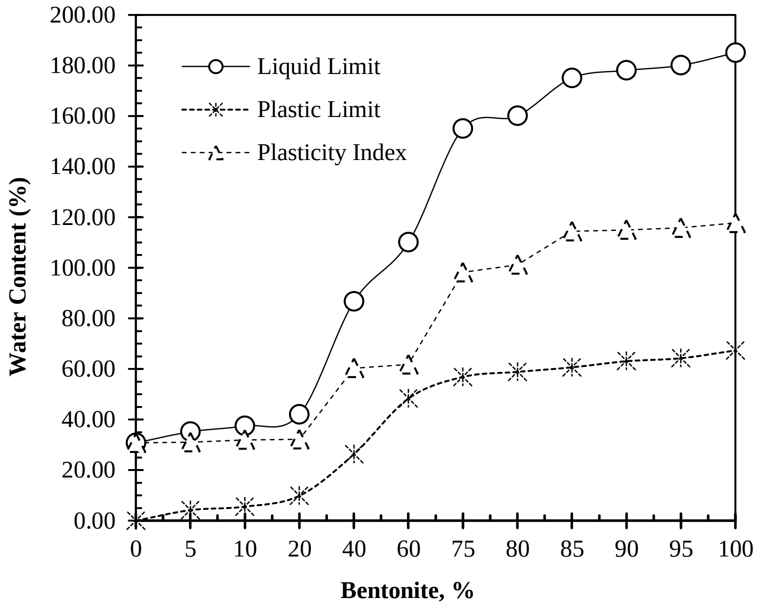

Fig. 4. Variation on liquid limit, plastic limit and plasticity index of sand with addition to bentonite

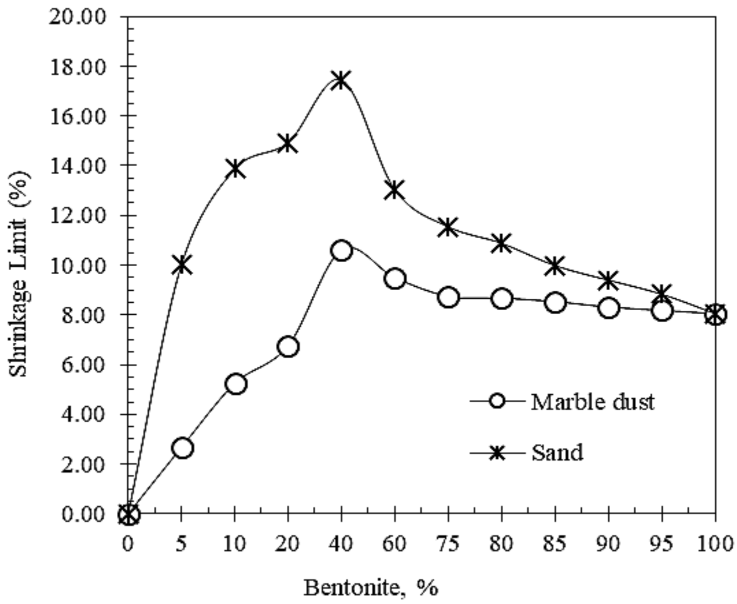

Fig. 5. Shrinkage limit of B-S and B-MD mixes

3.3 Compaction Characteristics of Bentonite with Marble Dust and Sand

Fig. 6 represents the compaction characteristics (ρ_{max} and OWC) of B-S and B-MD mixes.

It is observed that dry density of MD and S reduce from 1.87 gm/cc to 1.07 gm/cc and 1.58 gm/cc to 1.10 gm/cc with addition of bentonite up to 90%, respectively. However, OWC of MD and S enhances drastically with increase in bentonite percentage from 15.03% to 54.52% and 14.44% to 56.03% respectively (Fig. 6). Comparing the results of B-S and B-MD confirm the potential of marble dust to achieve the similar dry density and OWC than that of sand in combination of bentonite. The reduction in dry density with increment in bentonite is due to; (i) high surface charge of bentonite which resist the compactive effort, (ii) high repulsion capacity, and (iii) formation of diffuse double layer [25]. The reduction in dry density is very small up to the addition of 20% bentonite because the particles of bentonite fill the voids present in sand and marble dust. Further addition of bentonite causes a drastic reduction in dry density as an excess addition of bentonite occupies the outside space of sand and marble dust particles, resulting decrease in dry density.

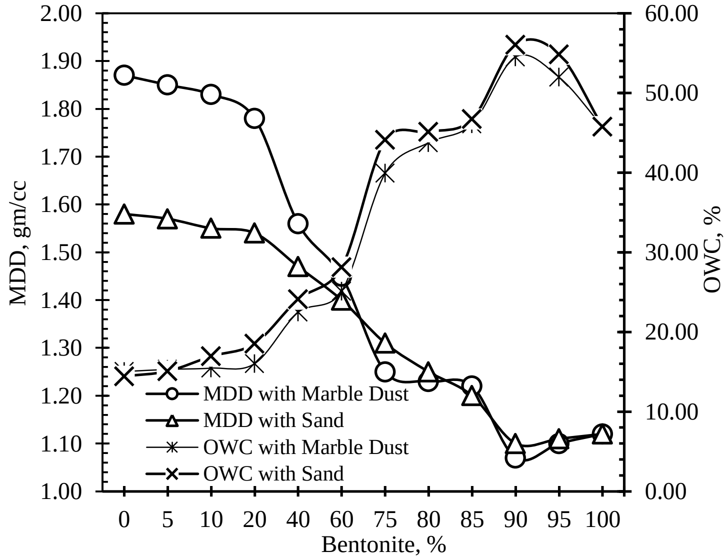

Fig. 6. Compaction characteristics of sand & marble dust with addition of bentonite

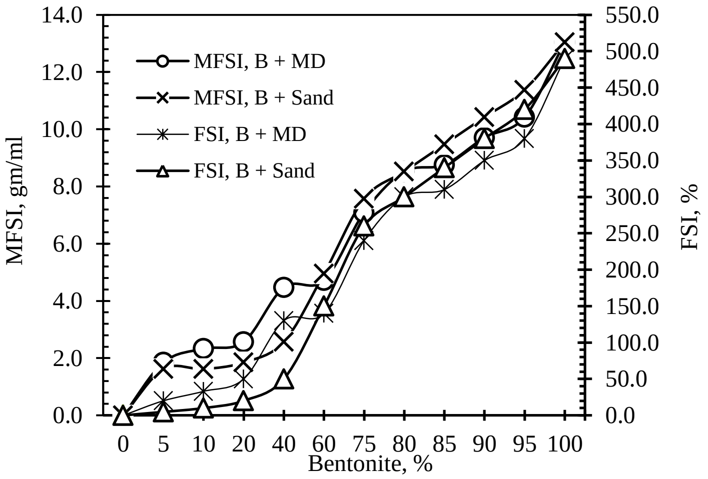

Fig. 7. Swell index (FSI and MFSI) of marble dust and sand with addition of bentonite

3.4 Swell Index of Bentonite with Marble Dust and Sand

Fig. 7 shows the swell indexes in terms of free swell index (FSI) and modified free swell index (MFSI) of B-S and B-MD mixes. It is observed that swell indexes of MD and S increase drastically from 0% to 420% and 0% to 380% with addition of bentonite up to 95%, respectively. Hence, swell indexes of B-MD is observed to be same as B-S mixes. This increment is due to addition of swelling particles of bentonite in nonswelling materials and increase in the thickness of diffuse double layer. Similar results are reported by previous researchers with sand-bentonite mixes.

4 Conclusion

Detailed study on the behaviour of varying percentage of bentonite with sand and marble dust has been done to understand the potential of marble dust to be used as a possible liner material. The major conclusions drawn from the present study are as follows:

1. The pH of sand and marble dust increases initially up to 20% and decreases after further addition of bentonite. Electrical conductivity increases continuously for sand and marble dust with increase in bentonite percentage. Both pH and EC of bentonite-sand and bentonite-marble dust mixes represent similar trend.
2. The plasticity index of marble dust and sand increases continuously with increase in percentage of bentonite. However, shrinkage limit of sand and marble dust increases up to 40% bentonite and reduces thereafter. Further, plastic behaviour of bentonite-sand and bentonite-marble dust mixes are almost identical.
3. The compaction characteristics (maximum dry density and optimum water content) of bentonite possess an identical behaviour with sand and marble dust. In both combination, OWC increases with reduction in dry density.
4. Increasing trends of swell indexes (FSI and MFSI) are observed in sand and marble dust in combination of bentonite.

This study confirms that marble dust shows similar behaviour as compared to sand in combination with bentonite. Hence, marble dust can be used as a possible liner material for waste containment. However, further study on the engineering properties of bentonite-marble dust needs to be done and has to be compared with behaviour of bentonite-sand mixes.

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