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Effect Of Wheat Straw Ash On The Plasticity Characteristics Of Jamshoro Shale

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ABSTRACT

This study investigates the effect of wheat straw ash (WSA) on the plasticity characteristics of Jamshoro shale. Shale samples were treated with WSA at 0%, 2%, 4%, 6%, 8%, 10%, and 12% by weight, and Atterberg limits were determined for each blend. Results showed that the Liquid Limit decreased progressively from 51% at 0% WSA to 44% at 12% WSA, while the Plastic Limit increased from 29% to 36% over the same range. Consequently, the Plasticity Index decreased markedly from 22% at 0% WSA to 8% at 12% WSA, representing a reduction of approximately 63.6%. These findings indicate that WSA treatment substantially reduces the plasticity of Jamshoro shale, likely due to cation exchange and flocculation-agglomeration reactions between the shale particles and the pozzolanic WSA, improving the soil's suitability for use in geotechnical applications such as subgrade and embankment construction.

Keywords: Wheat Straw Ash, Jamshoro Shale, Plasticity Index

INTRODUCTION

Shale is a fine-grained sedimentary rock composed predominantly of clay minerals, and is frequently encountered in geotechnical engineering practice across Sindh, including in the vicinity of Jamshoro. Owing to its clay mineralogy, shale often exhibits high plasticity, significant moisture sensitivity, and a marked tendency

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toward volumetric instability, expanding when wetted and shrinking upon drying. These characteristics pose considerable challenges for construction on or with shale, including reduced bearing capacity, differential settlement, and distress in overlying pavement and foundation structures. Consequently, shale is frequently classified as a problematic soil requiring stabilization before it can be reliably used in embankments, subgrades, or as a foundation material.

Soil stabilization techniques aim to improve the engineering behavior of such problematic soils, most commonly by reducing plasticity and moisture sensitivity while enhancing strength and volumetric stability. Traditional stabilizers such as lime and ordinary Portland cement (OPC) have long been employed for this purpose, typically acting through cation exchange, flocculation-agglomeration of clay particles, and pozzolanic reactions that bind soil particles into a more stable matrix. However, the production of lime and cement is energy-intensive and associated with substantial carbon dioxide emissions, prompting growing interest in sustainable, low-cost alternatives derived from agricultural and industrial waste streams.

Wheat straw ash (WSA), obtained through the controlled combustion of wheat straw, a major agricultural residue in wheat-growing regions such as Sindh and Punjab, Pakistan, is one such material. WSA contains significant amounts of amorphous silica, imparting pozzolanic reactivity that enables it to react with clay minerals in a manner similar to conventional stabilizers. When blended with clayey or shaley soils, WSA has been reported to alter the soil's Atterberg limits, typically reducing the Liquid Limit and Plasticity Index while increasing the Plastic Limit, indicating a reduction in plasticity and an improvement in workability. Given the large quantities of wheat straw generated annually as crop residue, often disposed of through open field burning with associated air quality concerns, its beneficial reuse in soil stabilization offers both an environmentally sound disposal route and an economical alternative to conventional stabilizers.

Despite encouraging findings for the use of agricultural ashes in stabilizing various clayey soils, research specifically addressing the effect of wheat straw ash on the plasticity behavior of Jamshoro shale remains limited. This study aims to address this gap by experimentally evaluating the influence of WSA, at varying percentages, on the Liquid Limit, Plastic Limit, and Plasticity Index of Jamshoro shale, with the objective of assessing its suitability as a sustainable stabilizing additive for this locally significant geomaterial.

MATERIALS AND METHODOLOGY

Soil

Jamshoro shale was collected from the vicinity of Mehran University of Engineering and Technology (MUET), Jamshoro, Sindh, Pakistan. The soil retained on the No. 40 sieve was discarded, and the remaining material was thoroughly mixed to ensure uniform testing conditions.

Table 1: Engineering Properties of Untreated Jamshoro Shale

Property	Standard	Value
Natural Moisture Content (%)	AASHTO T265	3.81

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Specific Gravity	ASTM D854	2.69
Liquid Limit (%)	ASTM D4318	51
Plastic Limit (%)	ASTM D4318	29
Plasticity Index (%)	ASTM D4318	22
USCS Classification	ASTM D2487	CH (high plasticity clay)
AASHTO Classification	—	A-7-6
Group Index (GI)	—	17

The Group Index of 17 exceeds the maximum allowable value of 10 for highway subgrade material, classifying the untreated Jamshoro shale as a poor subgrade material and confirming the need for stabilization.

Wheat Straw Ash (WSA)

Wheat straw, a widely available agricultural residue in Sindh, Pakistan, was burnt under controlled conditions at 600°C for 6 hours to produce wheat straw ash (WSA). The resulting ash was characterized using Energy Dispersive Spectrometry (EDS) to confirm its elemental composition and pozzolanic potential prior to use in stabilization.

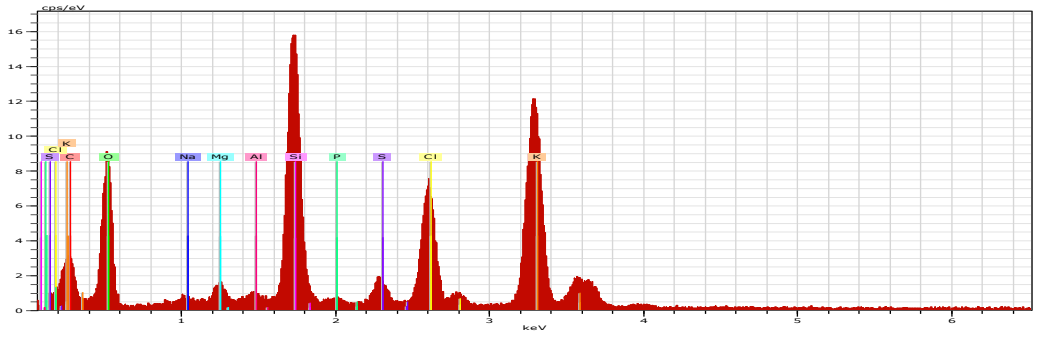

Figure 1: Energy Dispersive Spectrometer EDS of WSA at 600 C-6hr

Table 2: Weight Percentage of Elements in WSA (600°C–6hr)

Element	Series	Weight (%)	Error (%)
Silicon	K-series	32.57	0.6
Potassium	K-series	6.63	0.1
Calcium	K-series	0.52	0.4
Magnesium	K-series	0.41	0.1
Aluminium	K-series	0.31	0.3
Sodium	K-series	0.28	0.1

The relatively high silicon content (32.57%) confirms the amorphous silica-rich, pozzolanic character of the WSA produced under these calcination conditions, comparable to that observed for rice husk ash. The notably higher potassium content (6.63%) relative to RHA reflects the distinct mineral composition of wheat straw as a cereal crop residue.

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Soil-Ash Blending and Testing Program

WSA was thoroughly blended with untreated Jamshoro shale at 0%, 2%, 4%, 6%, 8%, 10%, and 12% by dry unit weight. Each blended sample was tested for Liquid Limit and Plastic Limit in accordance with ASTM D4318, and the Plasticity Index was calculated as the difference between the two (PI = LL − PL).

RESULTS AND DISCUSSION

Effect of WSA on Liquid Limit

Table 3: Effect of WSA Content on Liquid Limit, Plastic Limit, and Plasticity Index

WSA (%)	Liquid Limit (%)	Plastic Limit (%)	Plasticity Index (%)
0	51	29	22
2	49	31	18
4	48	32	16
6	47	33	14
8	46	34	12
10	45	35	10
12	44	36	8

Figure 2 shows the variation of Liquid Limit with WSA content. The Liquid Limit of the Jamshoro shale decreased progressively with increasing WSA content, from 51% at 0% WSA to 44% at 12% WSA, a reduction of approximately 13.7%. This reduction is attributed to cation exchange reactions between the calcium and potassium ions present in WSA and the exchangeable cations on the clay particle surfaces, promoting flocculation and agglomeration of the finer clay particles into coarser aggregations, which reduces the specific surface area available for water adsorption.

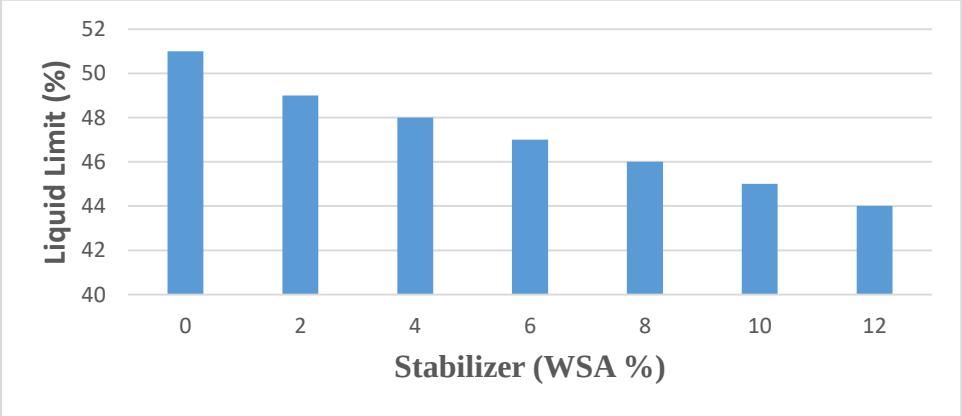

Figure 2: Liquid Limit vs. WSA Content (%)

Effect of WSA on Plastic Limit

Figure 3 presents the trend of Plastic Limit with increasing WSA content. The Plastic Limit increased steadily with WSA content, from 29% at 0% WSA to 36% at 12% WSA, an increase of approximately 24.1%. This increase reflects the coarser, more granular texture imparted by WSA particles, which alters the soil-water interaction at

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the plastic state and requires additional moisture for the blended material to reach a workable, plastic consistency.

Figure 3: Plastic Limit vs. WSA Content (%)

Effect of WSA on Plasticity Index

Figure 4 illustrates the combined effect of WSA content on the Plasticity Index. The combined effect of decreasing Liquid Limit and increasing Plastic Limit produced a marked reduction in Plasticity Index, from 22% at 0% WSA to 8% at 12% WSA, representing an overall reduction of approximately 63.6%. This reduction, while substantial, is somewhat less pronounced than that reported for rice husk ash on the same shale (approximately 73% at 12% replacement), which may be attributable to the lower silicon content and correspondingly lower pozzolanic reactivity of WSA (32.57% Si) compared to RHA (35.70% Si), as well as differences in ash particle morphology and calcination duration. Nonetheless, the results confirm that WSA is effective in reducing the plasticity of Jamshoro shale and improving its suitability as a subgrade material.

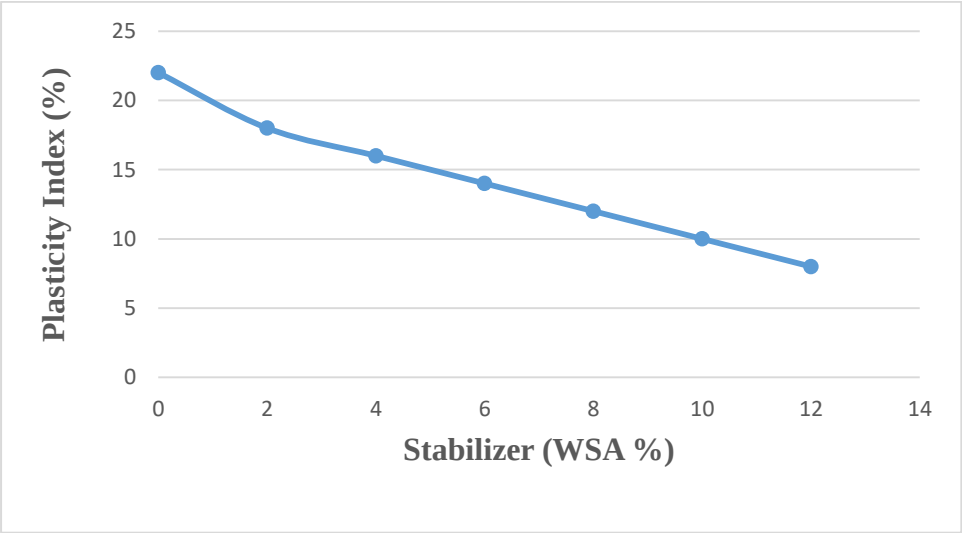

Figure 4: Plasticity Index vs. WSA Content (%)

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CONCLUSION

The untreated Jamshoro shale was classified as CH (inorganic clay of high plasticity) under the USCS and as A-7-6 under the AASHTO classification system, with a Group Index of 17, indicating a poor subgrade material requiring stabilization.

Wheat straw ash (WSA), produced by burning wheat straw at 600°C for 6 hours, was confirmed to be silica-rich (32.57% Si by EDS) and pozzolanic in nature, with a notably higher potassium content (6.63%) than typically observed in rice husk ash.

The Liquid Limit of the Jamshoro shale decreased progressively with increasing WSA content, from 51% at 0% WSA to 44% at 12% WSA, a reduction of approximately 13.7%.

The Plastic Limit increased with increasing WSA content, from 29% at 0% WSA to 36% at 12% WSA, an increase of approximately 24.1%.

The Plasticity Index decreased markedly, from 22% at 0% WSA to 8% at 12% WSA, a reduction of approximately 63.6%, indicating a substantial improvement in the workability and moisture stability of the shale.

This reduction, while significant, was somewhat lower than that achieved with rice husk ash on the same shale (approximately 73%), suggesting RHA may offer marginally greater plasticity reduction, likely due to its higher silica content and pozzolanic reactivity.

These trends are attributed to cation exchange and flocculation-agglomeration reactions between the WSA and the clay fraction of the shale, which reduce the soil's affinity for water and its tendency toward plastic deformation.

The results demonstrate that WSA is an effective and sustainable additive for reducing the plasticity of Jamshoro shale, improving its suitability for use as a subgrade or embankment material in highway construction.

Given the progressive nature of the improvement observed up to 12% WSA, further studies extending beyond this range, as well as direct comparative testing of WSA and RHA under identical conditions, are recommended to establish the optimum ash type and content for stabilizing Jamshoro shale.

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