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Influence of Micro Silica on Soil Stability and Plasticity: An Experimental Study

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Abstract - This experimental study investigates the effect of micro silica addition on the engineering properties of soil, focusing on parameters such as specific gravity, plastic limit, liquid limit, plasticity index, maximum dry density (MDD), and optimum moisture content (OMC). The results indicate that micro silica significantly influences soil characteristics, improving its stability while reducing plasticity. As micro silica content increased, the specific gravity initially decreased but later increased, showing a complex interaction between soil and micro silica. The plastic limit consistently decreased with increasing micro silica, indicating reduced soil plasticity and enhanced stability. Similarly, the liquid limit dropped from 62% to 52.4%, demonstrating the material's effect in decreasing water retention capacity and enhancing soil rigidity. The plasticity index showed an increase up to 20% micro silica, after which it slightly decreased, suggesting a nuanced relationship. The MDD initially decreased but showed slight increases at 20% and 30% micro silica before decreasing again at higher concentrations. OMC displayed fluctuations, with a peak at 10% micro silica, indicating varying moisture requirements for compaction. Overall, while micro silica enhances the soil's properties by reducing plasticity and increasing stability, the non-linear trends in specific gravity, MDD, and OMC suggest the need for further optimization in geotechnical applications.

***Key Words*:** Micro silica, soil properties, specific gravity, liquid limit, plastic limit, plastic index, maximum dry density, optimum moisture content, soil stabilization, soil compaction, geotechnical applications, construction materials, soil modification, engineering properties.

1.INTRODUCTION

Soil stabilization is a critical process in geotechnical and civil engineering, particularly when soils exhibit undesirable properties such as high plasticity, poor compaction characteristics, and low strength. To improve these properties, various stabilizing agents have been studied and used, one of the most promising being micro silica. Micro silica, a byproduct of silicon metal production, is a fine particulate material that has demonstrated significant effects on the physical and mechanical properties of soil. Its high surface area, pozzolanic activity, and ability to interact with soil particles make it an effective stabilizing agent for improving the strength, durability, and compaction characteristics of soils, particularly in applications requiring enhanced performance under load or challenging environmental conditions.

Micro silica is especially useful in addressing soil issues such as high plasticity, swelling, and poor compaction. The addition of micro silica to soil can influence a range of engineering properties, including specific gravity, liquid limit, plastic limit, plastic index, maximum dry density, and optimum moisture content (OMC). These properties play a crucial role in determining the suitability of a soil mixture for construction and geotechnical applications. However, the effects of varying micro silica content on these properties are not fully understood, and the behaviour of soil-micro silica mixtures can be complex, varying significantly based on the proportion of silica added.

Specific gravity is an important property in soil mechanics, reflecting the soil's overall density relative to water. The interaction between soil particles and micro silica can alter the packing and compactness of the soil, potentially affecting the soil's density. Studies have shown that adding micro silica can initially reduce the specific gravity of soil mixtures, which may indicate a reduction in the overall density of the mixture. However, at higher concentrations of micro silica, the specific gravity may increase, suggesting that silica can potentially contribute to the density of the mixture when present in higher amounts. Understanding these fluctuations is essential for determining the optimal micro silica content for specific engineering applications.

Liquid limit and **plastic limit** are key indicators of a soil's plasticity and workability. The liquid limit measures the water content at which soil transitions from a liquid to a plastic state, while the plastic limit defines the water content at which the soil becomes pliable but not mouldable. The reduction in both the liquid and plastic limits with increasing micro silica content suggests that the addition of silica reduces the soil's plasticity, making it less prone to deformation and more rigid. This improvement in soil stability can be beneficial in construction applications where soil needs to withstand loads and resist deformation over time.

The **plastic index**, which is the difference between the liquid and plastic limits, serves as an indicator of the soil's overall plasticity. An increase in the plastic index suggests a higher degree of plasticity, while a decrease indicates reduced plasticity. The fluctuating trends observed in the plastic index with varying micro silica content suggest that micro silica affects the relationship between the liquid and plastic limits in a complex manner. These changes could have important implications for soil behaviour under different loading conditions, influencing its compaction and strength characteristics.

The **maximum dry density** and **optimum moisture content (OMC)** are essential parameters for determining the compaction characteristics of soil. The maximum dry density represents the highest density a soil can achieve under a given compaction effort, while OMC refers to the water content at which soil achieves its maximum dry density. Variations in these properties with the addition of micro silica point to the complex interaction between soil particles and the silica, which can alter the soil's compaction behaviour and moisture retention capacity. The non-linear trends observed in both maximum dry density and OMC suggest that the effects of micro silica on these properties depend on the specific composition of the soil and the concentration of micro silica.

Overall, the addition of micro silica to soil offers the potential for significant improvements in soil stability, strength, and compaction characteristics, which are essential for geotechnical and construction applications. However, the effects of micro silica on soil properties are complex and depend on factors such as silica content and soil type. The findings from this study contribute to a deeper understanding of the role of micro silica in soil stabilization and highlight the need for further research to optimize its use in various engineering applications. Understanding the underlying mechanisms behind these changes will help in the development of guidelines for the effective use of micro silica in soil modification, ensuring improved performance and cost-effective solutions for construction and geotechnical projects.

2. LITERATURE REVIEW

The need for improving the properties of problematic soils, especially in the context of construction and geotechnical engineering, has led to significant advancements in soil stabilization techniques. Various studies have explored the potential of different materials to enhance the engineering properties of soils such as Black Cotton Soil (BCS), which is often characterized by high plasticity, poor compaction, and low strength. Stabilization methods using industrial waste materials and additives like Kota stone slurry, pond ash, sugarcane bagasse ash, fly ash, lime, and micro silica have shown promise in modifying these challenging soil properties for better use in engineering applications.

For instance, Er. Amit Kumar Jangid et al. (2018) observed that the addition of Kota stone slurry to BCS resulted in a decrease in the liquid limit (LL), plastic limit (PL), and plasticity index (PI). This decrease was attributed to the non-plastic nature of the Kota stone slurry, which also changed the classification of BCS from an inorganic soil of medium plasticity to an inorganic soil of low plasticity. Similarly, Er. Dharm Raj Senalka et al. (2018) noted that adding pond ash, a non-plastic material, reduced the LL, PL, and PI of BCS, again shifting the soil classification to low plasticity. The use of such non-plastic additives provides a way to reduce the water-holding capacity of the soil, which enhances its stability and workability in construction.

Himani Saini et al. (2019) also explored the effects of sugarcane bagasse ash (SCBA) on BCS, finding that as the proportion of SCBA increased, the LL, PL, and PI of the soil decreased. The low plasticity of SCBA contributed to this reduction, thus transforming the soil's behavior from high plasticity to low plasticity. This aligns with the broader trend observed in soil stabilization, where the introduction of low-plasticity or non-plastic materials can improve soil's stability and compaction characteristics, essential for its use in construction and infrastructure projects.

Further research by Er. Sunil Keshav et al. (2016) focused on the compaction behavior of BCS and Kota stone slurry mixtures, revealing that the maximum dry density (MDD) increased with the addition of Kota stone slurry up to 15%, after which it began to decrease. This suggests that while small quantities of Kota stone slurry improve compaction, excessive amounts may lead to a decrease in density. The fluctuation in compaction properties, as observed in various studies, highlights the complex relationship between soil composition and additive content, emphasizing the need for precise control over the proportion of additives used.

In a broader context, the use of industrial waste materials, such as fly ash and micro silica, in soil stabilization has gained increasing attention. Er. Amanpreet Tangri and Gagandeep et al. (2018) highlighted the use of blast furnace slag, fly ash, and other additives for ground improvement in problematic soils. Their work emphasizes the importance of using waste materials, both for their environmental benefits and cost-effectiveness, to enhance the properties of soil, making it suitable for construction purposes.

The use of micro silica, in particular, has shown promise in stabilizing soft clayey soils like BCS. According to Er. S.W. Thakare and Priti Chauhan et al. (2016), micro silica, a waste byproduct from electric arc furnaces, was found to improve the geotechnical properties of BCS, such as increasing strength and reducing plasticity when combined with lime and fly ash. Similarly, Er. Rehana Rasool et al. (2017) explored the use of Ground Granulated Blast Furnace Slag (GGBS) as an alternative to lime or cement to enhance the engineering characteristics of soils. The incorporation of such industrial byproducts not only improves soil stability but also addresses environmental concerns by utilizing materials that might otherwise contribute to waste.

3. MATERIAL AND METHODOLOGY

3.1 MATERIAL

1. **BLACK COTTON SOIL:** Soil are collected from village Pisegoan Dist- Durg.
2. **MICRO SILICA:** Ultrafine UF 100, Manufactured by ULTRAFINE MINERAL & ADMIXTURE PVT. LTD. Nagpur Maharashtra

3.2 METHODOLOGY ADOPTED

1. **Description of Sample:**

Table -1 Description of Soil Sample

S.No.	**Soil**	**Stabilizer %**
1	100%	0%
2	90%	10%
3	80%	20%
4	70%	30%
5	60%	40%
6	50%	50%

2. **PERFORMED TEST**

- Specific gravity
- Liquid limit
- Plastic limit
- Plasticity index
- Maximum dry density
- Optimum moisture content

4. RESULT AND DISCUSSION

4.1 Specific Gravity: The table presents the relationship between soil percentage, micro silica added percentage, and specific gravity. As the percentage of micro silica increases, the specific gravity shows variation, with values ranging from 2.16 to 2.5. The specific gravity decreases from 2.5 at 0% micro silica to 2.16 at 40% micro silica, and then increases again to 2.23 at 50% micro silica.

Table -2 Determination of Specific Gravity

S.No.	BCS %	Micro Silica Added (%)	Specific Gravity
1.	100	0	2.5
2.	90	10	2.16
3.	80	20	2.23
4.	70	30	2.39
5.	60	40	2.16
6.	50	50	2.23

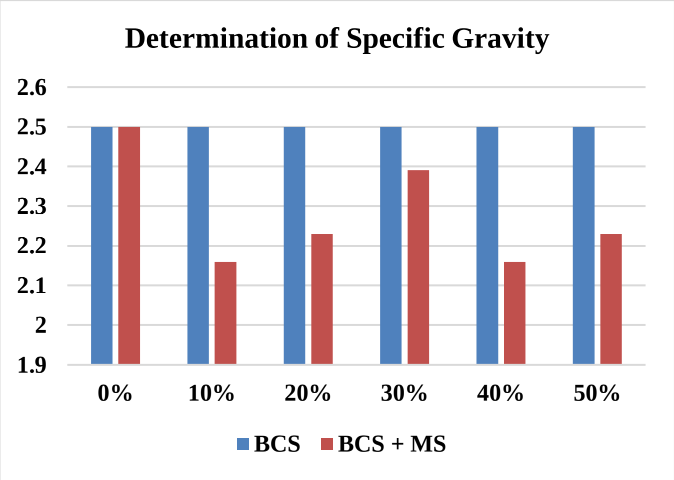


Fig. No. 1

4.2 Liquid Limit: The table shows the effect of Micro Silica addition on the Liquid Limit of soil. As the percentage of Micro Silica increases, the Liquid Limit decreases. With 0% Micro Silica (100% soil), the Liquid Limit is 62%. At 10% Micro Silica, the Liquid Limit decreases to 60.2%, and with 20% Micro Silica, it drops to 58.8%. Further increases in Micro Silica content led to a continued decrease in Liquid Limit: 56.2% at 30% Micro Silica and 54.6% at 40%. Finally, with 50% Micro Silica, the Liquid Limit reaches 52.4%. In summary, the addition of Micro Silica consistently reduces the Liquid Limit of the soil.

Table -3 Determination of Liquid Limit

S.No.	Soil %	Micro Silica Added (%)	Liquid Limit (%)
1.	100	0	62
2.	90	10	60.2
3.	80	20	58.8
4.	70	30	56.2
5.	60	40	54.6
6.	50	50	52.4

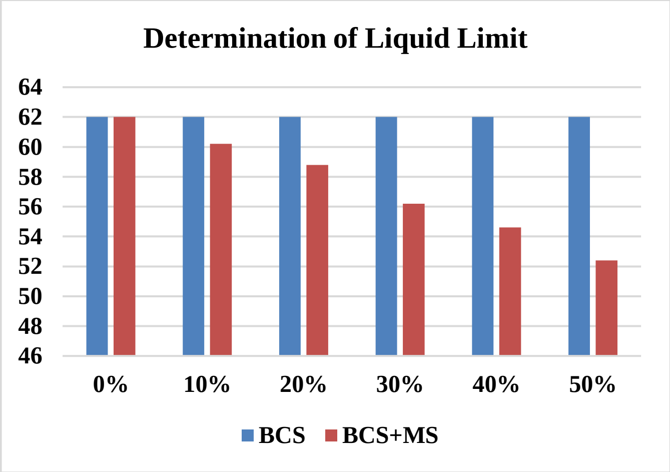


Fig. No. 2

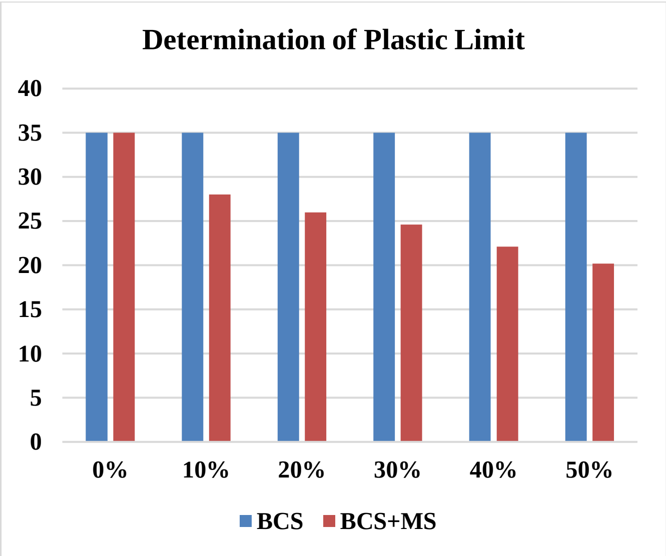
4.3 Plastic Limit: The study examined the effect of adding micro silica to soil and its impact on the plastic limit (PL). The results showed a consistent decrease in the plastic limit as the percentage of micro silica increased. Initially, with 100% soil and no micro silica, the plastic limit was 35%. As micro silica was gradually added, the plastic limit decreased: at 10% micro silica, the PL reduced to 28%; at 20% silica, it further dropped to 26%; and at 30%, it was 24.6%. With 40% micro silica, the PL decreased to 22.1%, and finally, at 50% micro silica, the plastic limit reached 20.2%. These findings indicate that the addition of micro silica progressively reduces the soil's plasticity, making the mixture less malleable and more stable, which is beneficial for construction and engineering applications.

Table -4 Determination of Plastic Limit

S No.	Soil (%)	Micro silica (%)	Plastic Limit (%)
1.	100	0	35
2.	90	10	28
3.	80	20	26
4.	70	30	24.6
5.	60	40	22.1
6.	50	50	20.2

Table -5 Determination of Plasticity Index

No.	Soil (%)	Micro silica Added (%)	Plasticity Index
1.	100	0	27
2.	90	10	32.2
3.	80	20	32.8
4.	70	30	31.6
5.	60	40	32.5
6.	50	50	32.2



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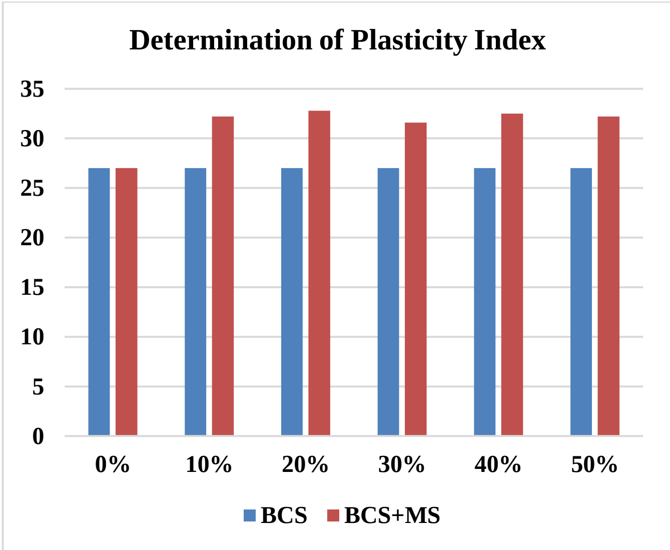

Fig. No. 4

4.4 Plasticity Index: The table illustrates the effect of adding Micro Silica on the Plasticity Index of soil. Initially, with 0% Micro Silica, the Plasticity Index is 27. As the Micro Silica content increases to 10%, the Plasticity Index rises to 32.2%, and it further increases to 32.8% with 20% Micro Silica. At 30%, the Plasticity Index slightly decreases to 31.6%, and with 40% Micro Silica, it rises again to 32.5%. Finally, at 50% Micro Silica, the Plasticity Index is 32.2%. In summary, the Plasticity Index increases with the addition of Micro Silica, peaking at 20%, before slightly decreasing with higher additions.

4.5 Maximum Dry Density: It shows the relationship between the percentage of soil, micro silica addition, and the resulting maximum dry density. The maximum dry density is highest at 1.69 when there is no micro silica (100% soil). As micro silica is added, the dry density initially decreases, reaching a low of 1.39 at 10% micro silica (90% soil). At 20% and 30% micro silica (80% and 70% soil), the density slightly increases to 1.47 and 1.64, respectively. However, at 40% and 50% micro silica (60% and 50% soil), the dry density drops again, showing a complex relationship between micro silica content and compaction**.**

Table -6 Determination of Maximum Dry Density

S No.	Soil %	Micro silica Added (%)	Maximum dry density (%)
1.	100	0	1.69
2.	90	10	1.39
3.	80	20	1.47
4.	70	30	1.64
5.	60	40	1.38
6.	50	50	1.62

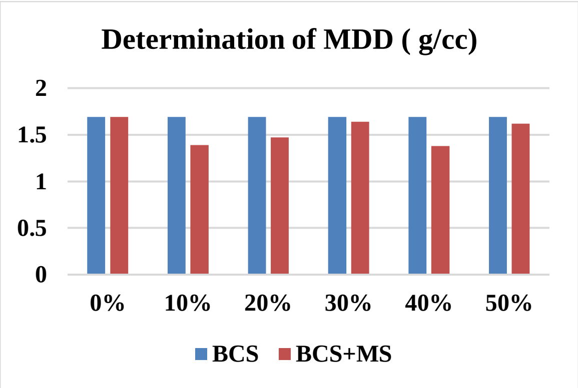

Fig. No. 5

4.6 Optimum Moisture Content: It presents the relationship between the percentage of soil, micro silica addition, and the optimum moisture content. The optimum moisture content (OMC) is highest at 32.10% when 10% micro silica is added (90% soil), indicating that small amounts of micro silica require more moisture for optimal compaction. As the micro silica percentage increases to 20% and 30% (80% and 70% soil), OMC values decrease to 21.05% and 25.00%, respectively. At higher micro silica levels (40% and 50%), the OMC increases again, reaching 44.44% and 18.18%, suggesting varying moisture requirements depending on the proportion of micro silica.

S No.	Soil %	Micro silica Added (%)	OMC (%)
1.	100	0	16.67
2.	90	10	13.4
3.	80	20	11.6
4.	70	30	11.2
5.	60	40	12.3
6.	50	50	10.89

Table -7 Determination of Optimum Moisture Content

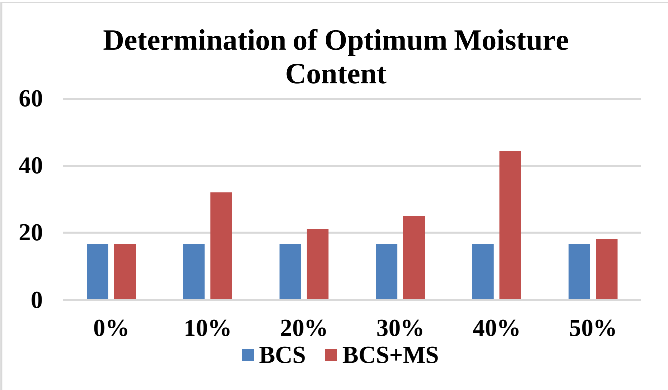

Fig. No. 6

5. CONCLUSION

The experimental study on the effect of micro silica addition to soil has provided valuable insights into its influence on various engineering properties. The results indicate that the addition of micro silica significantly affects the physical properties of the soil, including specific gravity, plastic limit, liquid limit, plasticity index, maximum dry density, and optimum moisture content (OMC).

1. **Specific Gravity**: The specific gravity of the soil-micro silica mixtures varied with the percentage of micro silica. Initially, as micro silica content increased from 0% to 10%, the specific gravity decreased from 2.5 to 2.16. However, it then increased with further

additions of micro silica, reaching 2.39 at 30%, before decreasing again at 40% and stabilizing at 50%. This suggests a complex interaction between soil and micro silica, influencing the density of the mixture.

2. **Plastic Limit**: The plastic limit decreased consistently as the percentage of micro silica increased. This indicates that micro silica reduces the plasticity of the soil, making the mixture more stable and less malleable. At 50% micro silica, the plastic limit was reduced to 20.2%, which is a significant decrease from the initial value of 35%.
3. **Liquid Limit**: The addition of micro silica also caused a steady decrease in the liquid limit, from 62% at 0% micro silica to 52.4% at 50% micro silica. This reduction suggests that micro silica enhances the rigidity of the soil, lowering its water retention capacity.
4. **Plasticity Index**: The plasticity index showed an increase with the addition of micro silica up to 20%, after which it slightly decreased. This fluctuation indicates a complex relationship between plasticity and silica content, which requires further investigation to understand its implications fully.
5. **Maximum Dry Density (MDD)**: The maximum dry density initially decreased with micro silica addition but showed slight increases at 20% and 30% micro silica, before decreasing again at 40% and 50%. This variation suggests that the relationship between silica content and soil compaction is complex and may be influenced by other factors.
6. **Optimum Moisture Content (OMC)**: The OMC fluctuated with increasing micro silica content. It reached its highest value at 10% micro silica (32.10%) and decreased as silica content increased, showing that higher amounts of micro silica require less moisture for compaction.

In conclusion, the addition of micro silica has a significant impact on the soil's engineering properties, improving its stability and reducing plasticity. However, the fluctuating trends in specific gravity, maximum dry density, and OMC suggest that the relationship between micro silica and soil properties is not linear, and further studies are required to optimize its use for specific geotechnical applications.

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