

Soil Stabilization by using Marble Dust and Iron Powder as Partial Replacement to Blackcotton Soil for Rural Road Development

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Abstract - Black cotton soil (BCS), widely distributed across India, is known for its high swelling and shrinkage characteristics, which pose serious challenges in construction, particularly in road subgrades and foundations. This study focuses on improving the engineering properties of BCS using marble dust (MD) and iron powder (IP), both of which are industrial waste materials, thereby promoting sustainable and economical soil stabilization techniques. Laboratory investigations were conducted to evaluate the effects of varying proportions of MD, IP, and their combination on key geotechnical properties such as specific gravity, Atterberg limits, Maximum Dry Density (MDD), Optimum Moisture Content (OMC), and shrinkage characteristics. The results indicate that specific gravity increases with the addition of stabilizers, with IP showing the highest increase, followed by MD, while their combination exhibits intermediate behavior. Marble dust proves highly effective in reducing the liquid limit, with 20% MD achieving the lowest value (18%), significantly improving soil stability. Iron powder is most effective in reducing shrinkage and plastic limits, with 20% IP yielding the lowest shrinkage limit (~5%) and plastic limit (~10%), indicating reduced volume change and plasticity. The combined MD and IP mix shows substantial improvement in compaction characteristics, with mixed sample achieving the highest MDD (2.07 g/cc) at the lowest moisture content (0.15%). Overall, the study demonstrates that marble dust and iron powder, individually and in combination, enhance the geotechnical performance of black cotton soil, making it more suitable for construction applications while also addressing environmental concerns through waste utilization.

Keywords: Black Cotton Soil (BCS), Soil Stabilization, Marble Dust (MD), Iron Powder (IP), Atterberg Limits, Maximum Dry Density (MDD), Optimum Moisture Content (OMC)

1. INTRODUCTION

Black cotton soil (BCS), widely distributed across the Deccan Plateau of India, is known for its high clay content and expansive nature due to the presence of montmorillonite minerals [15, 17]. Although it possesses good moisture retention and fertility, its significant swelling and shrinkage behavior under varying moisture conditions poses serious challenges for construction, particularly in road subgrades and foundations [13, 23]. These volume changes often lead to cracking, settlement, and structural instability, making soil stabilization essential [16, 25]. Soil stabilization is a technique used to improve engineering properties such as strength, durability, and bearing capacity [3, 22]. Traditional stabilizers like cement, lime, and

bitumen have been widely used [13, 15]; however, the growing emphasis on sustainability has encouraged the use of industrial waste materials [6, 17]. Among these, marble dust and iron powder have emerged as promising alternatives due to their availability, low cost, and environmental benefits [1, 4, 10, 25]. Marble dust, rich in calcium carbonate, improves soil properties through cation exchange, pozzolanic reactions, and carbonation [1, 4, 21]. It reduces plasticity, enhances maximum dry density, lowers optimum moisture content [20]. It also minimizes swelling and shrinkage behavior, making the soil more stable for construction applications [18, 21].

Iron powder, on the other hand, contributes to improved compaction, density, and shear strength by filling voids and increasing unit weight [2, 10, 25].

Its oxidation can provide minor bonding between particles [19]. However, its effectiveness in reducing swelling and plasticity is limited compared to conventional stabilizers, making it more suitable as a supplementary material rather than a primary stabilizer [14, 15].

1.1 Purpose of Research

The purpose of this research is to investigate the engineering properties of black cotton soil and examine the effects of blending it with marble dust and iron powder through experimental studies, with the aim of comparing the characteristics of natural soil against the modified mixture. By focusing on the improvements achieved through this blending, the study seeks to highlight the environmental benefits and sustainable potential of utilizing industrial waste materials in soil stabilization and rural road construction.

1.2 Need of Improvement

Black cotton soil is characterized by high plasticity and compressibility, leading to significant volume changes with variation in moisture content. When saturated, the soil expands and exerts upward pressure on structures, causing uplift and cracking. Conversely, during dry conditions, it shrinks, resulting in volume reduction and the formation of cracks. These shrink-swell characteristics adversely affect the performance of foundations and road pavements, making construction on such soils challenging and uneconomical due to their low bearing capacity. The presence of wide (100–150 mm) and deep (0.5–2 m) shrinkage cracks further weakens the soil structure. Swelling induces upward pressure, while shrinkage causes downward movement, both contributing to structural damage. Therefore, black cotton soil requires special treatment before being used in engineering applications. To address these issues, soil stabilization using cost-effective and locally available industrial waste materials has gained importance.

1.2.1 Black Cotton Soil

Black cotton soil is known for its shrink-swell characteristics, which can pose challenges for construction and agriculture. By incorporating marble powder, which is a waste product from the marble industry, the study likely aims to enhance soil stability, reduce shrinkage, and improve other relevant properties in a sustainable manner. This research could contribute to sustainable soil management practices and offer solutions for industries dealing with both soil and marble waste. Black cotton soil samples have been collected from Kokrud, Sangali district Region to ensure representativeness. The collected samples undergo laboratory tests to determine their physical and engineering properties, including

Atterberg limits, compaction characteristics, and strength parameters.

1.2.2 Marble Dust

Marble powder has been obtained from marble processing units and subjected to sieving to achieve the desired particle size distribution. The chemical composition of the marble powder will also be analyzed to assess its suitability as a soil additive. Marble dust, a by-product of the marble extraction and processing industry, holds significant importance in India, a leading global producer of marble. The country's abundant marble resources, particularly in states like Rajasthan, Gujarat, Andhra Pradesh, and Madhya Pradesh, contribute to the substantial generation of marble dust during cutting, grinding, and polishing operations. Comprised mainly of finely ground calcium carbonate, marble dust boasts diverse applications across several sectors. In construction, it serves as a valuable filler material in concrete and mortar, enhancing their workability, durability, and aesthetic appeal. Artists and sculptors utilize marble dust as a sculpting medium or additive to achieve specific textures or finishes, while manufacturers employ it in various products such as tiles, ceramics, plastics, and paper, often as a pigment or filler.

1.2.3 Iron powder

Iron powder is collected from iron processing and manufacturing industries and then sieved to obtain the required particle size. Its chemical composition is analyzed to check whether it is suitable for use as a soil additive. Iron powder is a by-product produced during cutting, grinding, and machining of Iron. In India, large iron and steel industries in states like Odisha, Jharkhand, Chhattisgarh, and Karnataka generate a significant amount of this powder. It consists mainly of very fine iron particles. In civil engineering, iron powder can be mixed with Black Cotton Soil to improve soil properties such as strength, density, and stability. Besides soil improvement, iron powder is also used in powder metallurgy, magnetic materials, and other industrial processes. Additionally, in agriculture, marble dust finds use as a soil amendment to improve structure, pH balance, and nutrient content.

2. LITERATURE REVIEW

K. Shyam Chamberlin et al.,^[8] (2024), this study presents the results of a laboratory investigation on how different dusts affect the strength and durability of expansive soil stabilized with rice husk ash (RHA). Adding 35% marble dust reduced the soil's liquid limit by about 33%, while 10% RHA reduced it by 48%. The plastic limit of the soil decreased by 25% with 35% marble dust, and the free swell index was also significantly improved with marble dust. The California Bearing Ratio (CBR) of the soil increased by around 40% when 30–35% marble dust

was added. Overall, both marble dust and rice husk ash were effective in stabilizing the expansive soil. This method is cost-effective and helps reduce structural damage because both materials are locally available and inexpensive. Among the two, marble dust was found to be more efficient than rice husk ash in improving the soil properties.

Muzamil Majeed and Aman Preet Tangri ^[11] (2021), in this review paper different industrial waste use for stabilization of soil has been explained. The study highlights that these wastes help solve disposal problems while improving soil properties. Fly ash is widely used to stabilize soil and form strong base layers, while cement kiln dust enhances plastic limits, reduces moisture content, and increases bearing capacity. Stabilized soils showed very high CBR values (>80%) and improved mechanical properties such as strength, toughness, and durability, making them suitable for low-cost construction and road subgrade applications.

Rajshekar Rathod et al., ^[16] (2024), it observed from this paper is that direct shear strength test that as marble dust and bioenzyme content in the blended soil sample is increased, three times increase in the angle of internal friction (ϕ) and 71.82% increase in cohesion (C) is observed for soil sample of blend as compared to virgin soil I sample. This is due to particle interlocking, providing a binding effect, and promoting improved compaction. Unconfined compression strength for blended Soil sample increases with percentage when compared to Unconfined compression strength of virgin soil sample. This significant increase in strength attributed to the chemical reactions that occur between the calcium content in marble dust and bioenzyme and the silica and alumina present in the Soil. These reactions lead to the formation of cementitious compounds. Also the addition of marble dust to soil which led to decrease in plasticity and water-holding capacity and reduced shrinkage potential. These enhancements in the soil's characteristics improve its strength and stability, making it more suitable for various engineering applications.

P. Ashween Kumar et al., ^[14](2023), this research focused on evaluating the engineering behavior of black cotton soil when mixed with waste iron ore powder. The soil sample was collected from Ghatkesar Mandal in the Medchal–Malkajgiri region, and the iron ore powder was obtained from a local small-scale industry. The soil was blended with iron ore powder in varying proportions of 0%, 5%, 10%, 15%, and 20%. The test results indicated consistent improvement in soil properties with the addition of iron ore powder. Specific gravity increased gradually, showing about a 10.63% rise at 20% replacement. The liquid limit decreased significantly, with a reduction of 21.73% at 20% iron ore content, making the soil more suitable for

construction applications. Similarly, the plasticity index decreased by 34.39%, indicating reduced plastic behavior and improved stability. Compaction characteristics also showed positive changes. At 20% replacement, the maximum dry density increased by 6.45%, while the optimum moisture content decreased by 21.87%. Overall, the findings confirm that discarded iron ore powder can effectively enhance the engineering properties of black cotton soil and improve its performance as a subgrade material.

Sara Abdullah et al.,^[19] (2023), studied the use of waste marble powder as a partial replacement for cement and iron ore powder as a replacement for sand in concrete. The results showed that optimum strength was achieved with 10% marble powder and 50% iron powder, improving both compressive and flexural strength. The study also found that self-compacting concrete with 10–15% marble powder performed better than conventional concrete. Overall, the use of these waste materials enhances concrete properties while reducing environmental impact, making it a sustainable and cost-effective solution for construction.

Sachin N. Bhavsar et al.,^[18] (2014), this study explains that black cotton soil is an expansive soil because it swells when it absorbs water and shrinks when it dries. The swelling and shrinkage behavior of black cotton soil reduces its strength and makes it unsuitable for construction. Replacing it entirely with non-expansive soil is costly, so stabilization using waste marble powder is a practical alternative. In this study, a mix of 50% black cotton soil and 50% marble powder was tested using Atterberg limits, particle size distribution, free swell index, and linear shrinkage tests. The results showed a significant reduction in swelling and shrinkage, along with improved engineering properties. Thus, the use of marble powder effectively enhances soil stability while also promoting sustainable waste utilization.

3. LABORATORY SET UP

3.1 Material Collection

3.1.1 Black Cotton Soil

Black Cotton soils are inorganic clays of medium to high compressibility and form a major soil group in India. Black Cotton soil has a high percentage of clay, which is predominantly Montmorillonite in structure and black or blackish grey in color. Because of its high swelling and shrinkage characteristics, the black Cotton soil has been a challenge to geotechnical and highway engineers. The soil is very hard when dry, but loses its strength completely when in wet condition. The wetting and drying process causes vertical movement in the soil mass which leads to failure of a pavement, in the form of settlement, heavy depression, cracking and

unevenness. It also forms clods which cannot be easily pulverized as treatment for its use in road construction (Holtz & Gibbs 1956). This poses serious problems as regards to subsequent performance of the road. Gradual intrusion of wet Black Cotton soil invariably leads to failure of the road. However, since this soil is available easily at low cost, it is frequently used for construction purposes (Bell, 1988). Some of the factors which influence the behaviour of these expansive soils are initial moisture content, initial dry density, amount and type of clay, Atterberg's limits of the soil, and swell potential.



Fig -1: Sampling of Black cotton soil on location.

Table -1: Laboratory evaluated properties of pure Black cotton soil.

Sr. No.	Property	Result
1	Colour	Grey-Black
2	Specific Gravity	2.57
3	Water Content	28.35%
4	Liquid Limit	75%
5	Plastic Limit	30.58%
6	Shrinkage Limit	19.25%
7	Plasticity Index	44.42%
8	Consistency Index	1.05
9	Liquidity Index	-0.05
10	MDD	1.305 kN/m ³
11	OMC	30.50%

3.1.2 Marble dust

Marble dust, a by product of the marble extraction and processing industry, holds significant importance in India, a leading global producer of marble. The country's abundant marble resources, particularly in states like Rajasthan, Gujarat, Andhra Pradesh, and Madhya Pradesh, contribute to the substantial generation of marble dust during cutting, grinding, and polishing operations. Comprised mainly of finely ground calcium carbonate, marble dust boasts diverse applications across several sectors. In construction, it serves as a valuable filler material in concrete and mortar, enhancing their workability, durability, and aesthetic appeal. Artists and sculptors utilize marble dust as a sculpting medium or additive to achieve specific textures or finishes, while manufacturers employ it in various products such as tiles, ceramics, plastics, and paper, often as a pigment or filler. Additionally, in agriculture, marble dust finds use as a soil amendment to improve structure, pH balance, and nutrient content heracing marble dust into black cotton soil for stabilization can have several beneficial effects.



Fig -2: Collected marble dust sample.

Table -2: Chemical properties of marble dust.

Sr. No.	Property	Result
1	Colour	White
2	Specific Gravity	2.67
3	Bulk Density	1200 kg/m ³
4	Fineness	85 %
5	Calcium Carbonate	90 %
6	Moisture Content	0.5 %
7	Water Absorption	< 1 %
8	pH Value	8

3.1.3 Iron powder

For road construction, adding iron powder to black cotton soil can influence some engineering properties, but its effectiveness is limited compared with common stabilizers. Black cotton soil, widely found in parts of Maharashtra in India, contains clay minerals such as Montmorillonite that cause high swelling and shrinkage. When iron powder is mixed with this soil, it can slightly increase soil density and improve shear strength because the fine iron particles fill the voids between soil particles. Over time, the iron may oxidize and form iron oxides, which can help bind some particles together and slightly improve soil stability. However, iron powder does not significantly reduce the swelling and shrinkage behavior of black cotton soil, which is a major problem for road subgrades. Because of this, its improvement effect on bearing capacity and durability of roads is generally small. For effective stabilization in road construction, materials such as lime, cement, or fly ash are more commonly used because they significantly reduce plasticity, swelling, and moisture sensitivity



Fig -3: Collected iron powder sample.

Table -3: Chemical properties of iron powder.

Sr. No.	Property	Result
1	Colour	Reddish-brown
2	Specific Gravity	5.3
3	Bulk Density	1400 kg/m ³
4	Particle Size	1 – 100 μm
5	Fineness	80 %
6	Moisture Content	< 2 %
7	Iron Oxide	85 %

8	pH Value	7
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3.2 Methodology

The basic laboratory tests—namely specific gravity, sieve analysis, Atterberg limits, and compaction tests—were conducted on black cotton soil as well as on soil blended with marble dust and iron powder to evaluate their fundamental properties. Soil stabilization was carried out by adding marble dust and iron powder in varying proportions of 5%, 10%, 15%, and 20%. Based on the results, the optimum percentage of marble dust and iron powder was determined. The results obtained from all mixes were compared to identify the most suitable additive proportion for improving soil properties. All tests and analyses were carried out in accordance with IS 2720 standards. Incremental addition of marble dust and iron powder allowed clear observation of their influence on soil behavior at each concentration level. Furthermore, the study provides insights into the potential of industrial waste utilization for sustainable construction practices, ensuring reduced environmental impact. The findings contribute to developing practical guidelines for rural road stabilization projects and highlight the role of innovative material blends in enhancing soil performance.

3.3 Sample Preparation

- The collected soil sample is first dried in direct sunlight to remove natural moisture. Soil clods are broken manually using a wooden mallet to obtain a uniform sample. Organic matter such as roots, leaves, and other impurities are removed carefully.
- The soil is sieved from 4.75 mm to achieve uniform particle size distribution.
- The cleaned soil sample is then placed in an oven for drying at a temperature of 105°C for 24 hours to remove residual moisture.
- After oven drying, the sample is cooled at room temperature before further handling.
- The required quantity of soil for each test is measured accurately using a weighing balance.
- Marble dust and iron powder are added as stabilizing agents by partially replacing the weight of soil.
- Proper mixing of soil and additives is carried out to achieve a homogeneous blend.
- Four different mixes are prepared by replacing soil with marble dust and iron powder in varying proportions: (5% ,10% ,15% ,20%)

- The prepared blends are then used for conducting various laboratory tests such as Atterberg limits, compaction, and strength tests.

4 RESULTS AND DISCUSSIONS

1.1 Variation of Specific Gravity with Different Blends.

Table -4: Results of specific gravity with different blends.

Sr. No.	Blend Type	Specific Gravity
1	Original Soil	1.66
2	M1	1.75
3	M2	1.83
4	M3	1.91
5	M4	2.00
6	I1	2.53
7	I2	3.00
8	I3	3.28
9	I4	4.00
10	M1-I1	2.20
11	M2-I2	2.40
12	M3-I3	2.60
13	M4-I4	3.00

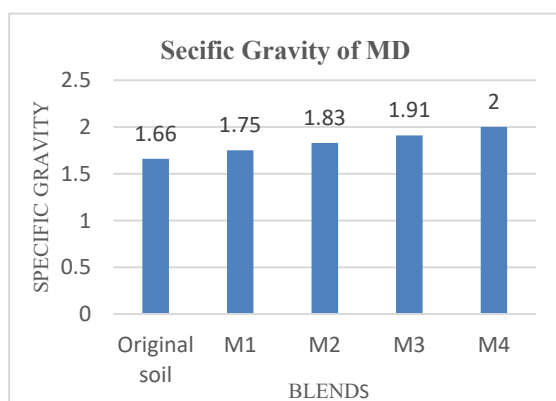


Fig-4: Specific Gravity Variation of BCS with MD

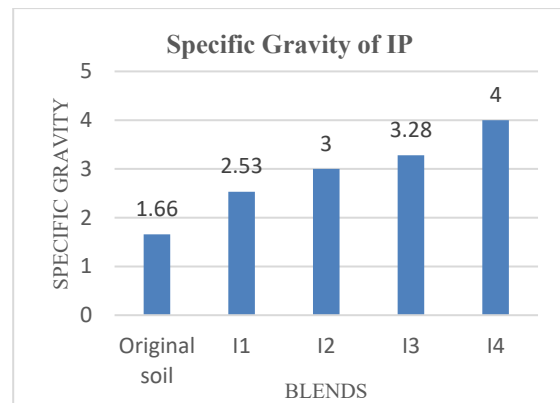


Fig -5: Specific Gravity Variation of BCS with IP

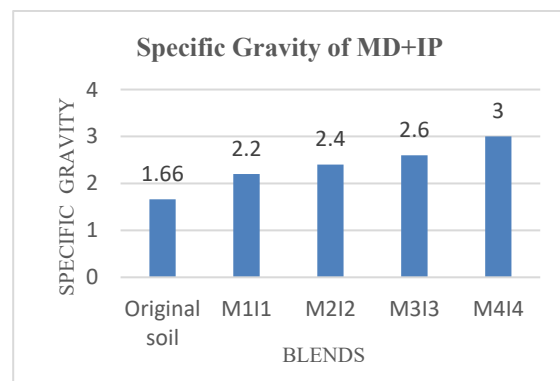


Fig -6: Specific Gravity Variation of BCS with MD+IP

The variation of specific gravity for different blends is presented in Table 4.1. The specific gravity of the original soil was found to be 1.66. With the addition of material marble dust (M1 to M4), a gradual increase in specific gravity was observed, reaching a maximum value of 2.00 for M4. This indicates that the material marble dust contributes to densification and improves the overall particle packing of the soil. Similarly, the inclusion of material iron powder (I1 to I4) resulted in a significant increase in specific gravity, ranging from 2.53 to 4.00. This higher increase suggests that material iron powder possesses a greater density compared to the original soil and material marble dust. For the combined blends (M1I1 to M4I4), the specific gravity values ranged from 2.20 to 3.00, showing a consistent improvement over the original soil. However, these values are lower than those of individual iron powder blends, indicating a balanced interaction between the two materials.

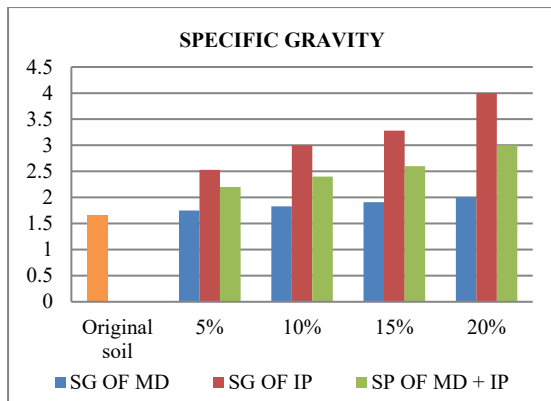


Fig -7: Comparative Analysis of Specific Gravity of BCS with different blends.

The chart illustrates how specific gravity changes with increasing percentages (5%–20%) for MD, IP, and their combined mix. All three show a gradual upward trend as the percentage increases, with the combined MD+IP values consistently lying between the individual MD and IP values. Specific gravity increases with increasing percentage for all samples. IP shows the highest specific gravity at each level, MD shows the lowest, and the MD+IP mix gives intermediate values. At 20%, the values reach their maximum for all three. The increase in specific gravity suggests that the material becomes denser as the percentage rises. IP contributing higher values indicates it has a greater inherent density compared to MD. The blended sample (MD+IP) reflects a balanced behavior, combining properties of both materials. This trend indicates improved compaction or reduced void spaces with higher percentages, which may enhance the material’s engineering performance in applications like construction or soil stabilization

4.2 Variation of Liquid Limit with Different Blends.

Table-5: Results of Liquid limit with different blends

Sr. No.	Blend Type	Liquid Limit(%)
1	Original Soil	82
2	M1	50
3	M2	41
4	M3	25
5	M4	18
6	I1	78
7	I2	59

8	I3	33
9	I4	32
10	M1–I1	22
11	M2–I2	27
12	M3–I3	66
13	M4–I4	67

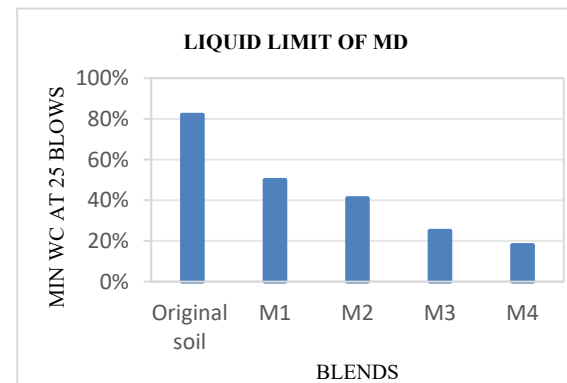


Fig -8: Variation of Liquid Limit of BCS with MD

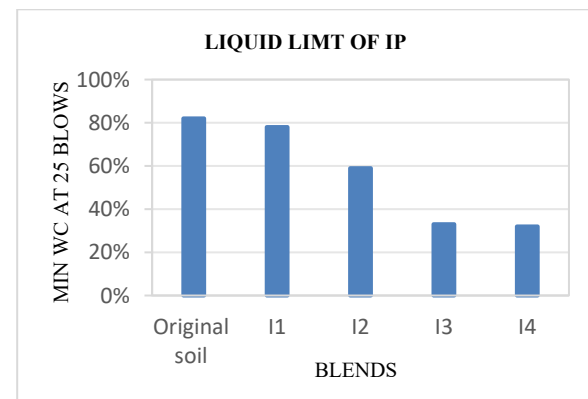


Fig -9: Variation of Liquid Limit of BCS with IP

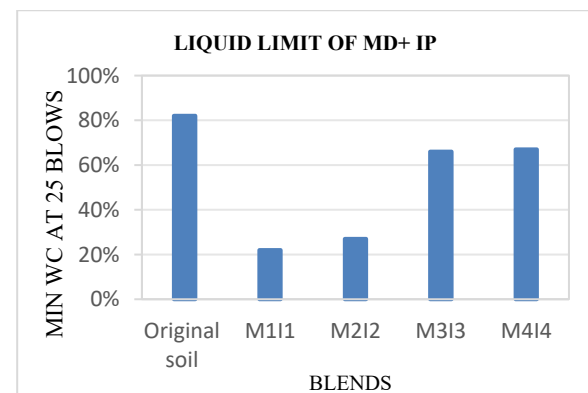


Fig -10: Variation of Liquid Limit of BCS with MD+IP

The Liquid Limit (LL) of different blends is shown in Table 4.2. The original soil exhibits a high Liquid

Limit of 82%, indicating high clay content and moisture retention. Addition of material marble dust (M1–M4) progressively decreases the LL, reaching 18% for M4, suggesting that marble dust reduces the soil’s plasticity and water absorption potential. Material iron powder (I1–I4), in contrast, maintains relatively high LL values (32–78%), indicating its fine-grained nature and ability to retain moisture. The combined blends (M–I) show intermediate LL values, ranging from 22% to 67%, demonstrating a moderating effect between the two materials. Overall, these results indicate that incorporating stabilizing materials can effectively modify the soil’s liquid limit, which is important for improving soil workability, reducing susceptibility to shrinkage, and enhancing engineering performance in construction applications.

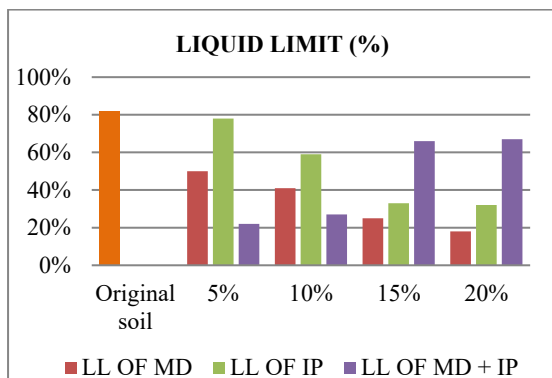


Fig -11: Comparative Analysis of of Liquid limit BCS with different blends.

The chart shows the variation in liquid limit (LL) of the original soil and soil treated with MD, IP, and a combination of MD+IP at different percentages (5%, 10%, 15%, and 20%). The original soil has a high LL (around 80%), indicating high plasticity and likely poor engineering performance. With the addition of MD alone, the LL decreases progressively as the percentage increases (from ~50% at 5% to ~18% at 20%). This suggests MD effectively reduces soil plasticity, likely due to flocculation and reduced water affinity. For IP alone, the LL initially remains relatively high at 5% (~78%) but then decreases steadily to about 32% at 20%. This indicates IP also improves the soil but is less effective than MD at lower dosages. In contrast, the combination of MD+IP shows a different trend: LL increases significantly with higher percentages (from ~22% at 5% to ~68% at 20%). This may indicate interaction effects that increase water retention or alter soil structure unfavorably at higher combined contents. Overall, MD appears to be the most effective stabilizer in reducing liquid limit, especially at higher dosages, while IP shows moderate improvement. The combined treatment does not yield synergistic benefits and may even increase plasticity at higher percentages.

4.3 Variation of Plastic Limit with Different Blends.

Table-6: Results of Plastic Limit with different blends

Sr. No.	Blend Type	Plastic Limit (%)
1	Original Soil	39
2	M1	33
3	M2	23
4	M3	13
5	M4	11
6	I1	45
7	I2	41
8	I3	16
9	I4	10
10	M1–I1	21
11	M2–I2	19
12	M3–I3	36
13	M4–I4	27

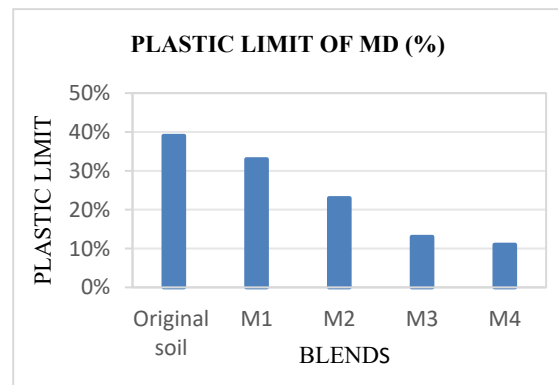


Fig -12: Variation of Plastic Limit of BCS with MD

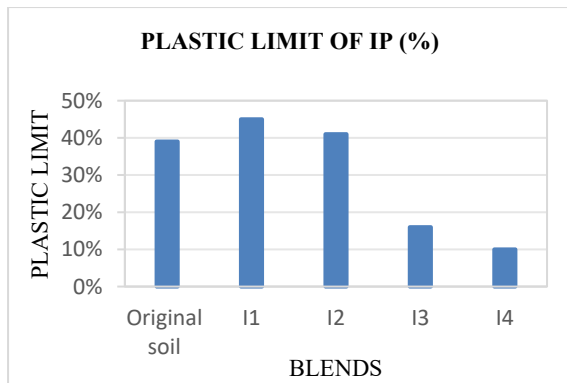


Fig -13: Variation of Plastic Limit of BCS with IP

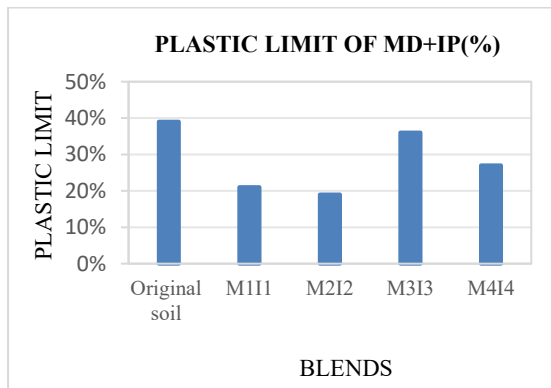


Fig -14: Variation of Plastic Limit of BCS with MD+IP.

The Plastic Limit values of different blends are presented in Table 4.3. The original soil has a Plastic Limit of 39%. With the addition of material marble dust (M1–M4), the Plastic Limit decreases gradually, reaching a minimum of 11% for M4. This indicates that material marble dust reduces the soil’s plasticity, likely due to a lower clay content or increased sand fraction. On the other hand, material iron powder (I1–I4) shows higher Plastic Limit values, ranging from 10% to 45%, reflecting its inherent moisture-retaining properties. The combined blends (M–I) show intermediate Plastic Limit values, varying from 19% to 36%, suggesting that the interaction between the two materials moderates the soil plasticity. Overall, the addition of these stabilizing materials influences the soil’s plastic behavior, which can improve workability and reduce susceptibility to shrink-swell behavior in engineering applications.

The chart demonstrates the impact of three different modifications—PL OF MD, PL OF IP, and PL OF MD+IP—on the soil’s Plastic Limit (PL) across concentrations ranging from 5% to 20%.

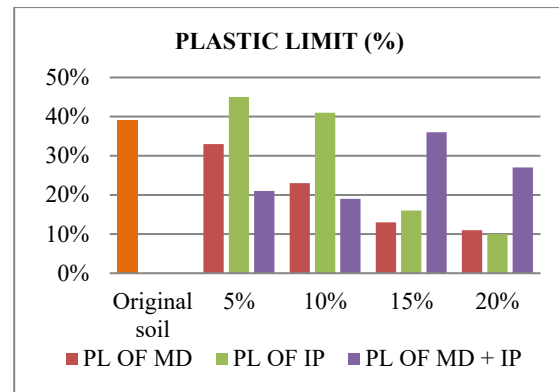


Fig -15: Comparative Analysis of of plastic limit BCS with different blends.

The original soil starts with a relatively high plastic limit of approximately 39%. For the MD modification, there is a steady and consistent decrease in PL as the percentage increases, reaching a minimum of about 11% at the 20% dosage. In contrast, the IP modification initially increases the plastic limit to a peak of 45% at 5% concentration before dropping sharply to the overall lowest value of 10% at the 20% level. The combined MD+IP modification shows more erratic behavior; it initially drops to 21%, spikes significantly to 36% at the 15% concentration, and finally settles at 27% at the 20% dosage. Overall, the data indicates that while the additives generally reduce the soil’s plasticity at higher concentrations, 20% IP is the most effective at lowering the plastic limit, thereby potentially reducing the soil’s susceptibility to moisture-induced volume changes.

4.4 Variation of Shrinkage Limit with Different Blends.

Table -7: Results of Shrinkage Limit with different blends

Sr. No.	Blend Type	Shrinkage Limit(%)
1	Original Soil	34
2	M1	30
3	M2	15
4	M3	12
5	M4	6
6	I1	32
7	I2	12
8	I3	9

9	I4	5
10	M1-I1	20
11	M2-I2	16
12	M3-I3	10
13	M4-I4	6

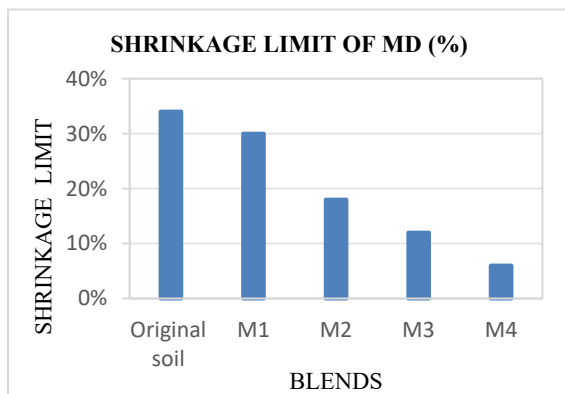


Fig -16: Variation of Shrinkage Limit of BCS with MD.

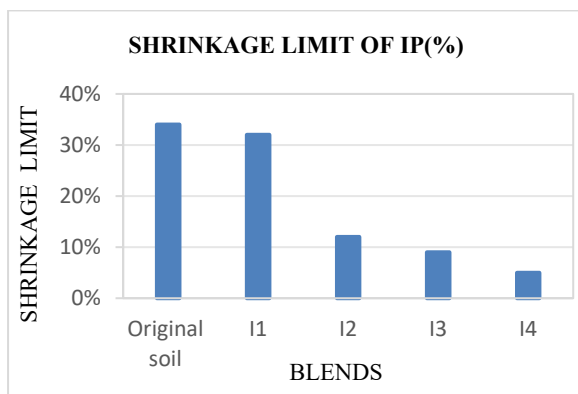


Fig-17: Variation of Shrinkage Limit of BCS with IP.

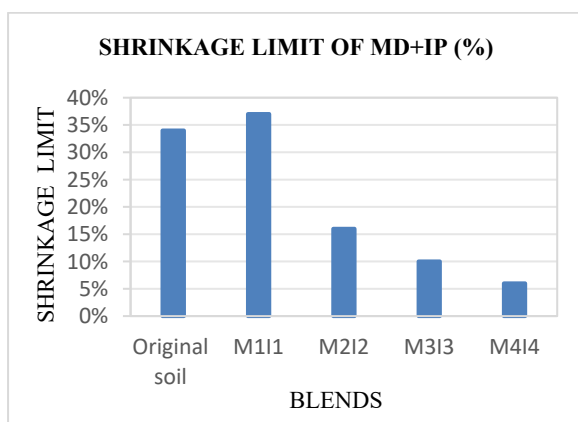


Fig -18: Variation of Shrinkage Limit of BCS with MD+IP.

The Shrinkage Limit (SL) values for different blends are presented in Table 4.4. The original soil has a Shrinkage Limit of 34%, indicating moderate potential for volume change upon drying. Addition of material marble dust (M1–M4) reduces the SL progressively, reaching a minimum of 6% for M4, suggesting a reduction in soil’s resistance to shrinkage. Material iron powder (I1–I4) shows relatively higher SL values for the first blend (32% for I1), but lower values for subsequent blends, indicating that the influence of iron powder on shrinkage varies depending on its proportion. The combined blends (M–I) exhibit intermediate SL values ranging from 6% to 20%, reflecting the moderating interaction between the two materials. Overall, the results demonstrate that the addition of stabilizing materials significantly affects the soil’s shrinkage behavior, which is critical for predicting volume change, controlling cracking, and improving stability in engineering applications. These findings emphasize the importance of optimizing blend proportions to achieve desired shrinkage resistance, ensuring soil stability and minimizing risks of cracking in engineering applications.

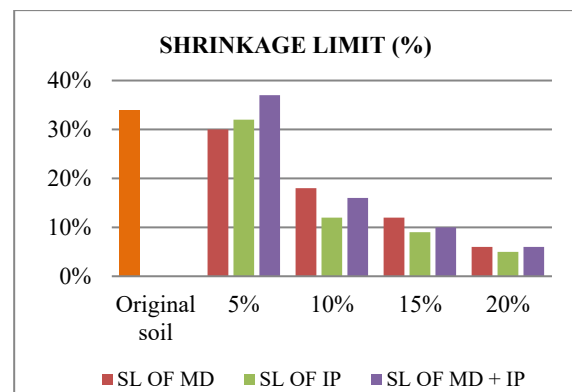


Fig -19: Comparative Analysis of Shrinkage limit with different blends.

The bar graph shows that the shrinkage limit of soil decreases consistently with the addition of additives. Original soil has the highest shrinkage limit, indicating greater resistance to volume change. As additive percentages increase (5%, 10%, 15%, 20%), the shrinkage limit reduces across all categories (SL of MD, SL of IP, SL of MD+IP). The combined effect of MD + IP shows the lowest shrinkage limit values, highlighting a stronger influence when both additives are present. This trend suggests that additives reduce the soil’s ability to resist shrinkage. The reduction is progressive with higher additive content, meaning the soil becomes more prone to volume changes. From a geotechnical perspective, this implies that while additives may improve certain properties, they compromise shrinkage resistance. The combined additives (MD + IP) have a synergistic effect, leading to the most significant reduction in shrinkage limit.

4.5 Variation of Coefficient of Uniformity (Cu), Coefficient of Curvature (Cc), and Fineness Modulus (FM) with Different Blends.

Table-8: Results of Variation of Coefficient of Uniformity (Cu), Coefficient of Curvature (Cc), and Fineness Modulus (FM) with different blends.

Sr.No.	Blend Type	Cu	Cc	FM
1	Original Soil	1.34	43	5.71
2	M1	1.44	30	5.93
3	M2	1.54	34	7.37
4	M3	1.51	27	7.71
5	M4	1.49	25	7.75
6	I1	1.24	56	7.25
7	I2	1.33	31	7.80
8	I3	1.36	90	8.51
9	I4	1.38	38	7.66
10	M1-I1	1.92	22	7.38
11	M2-I2	1.95	18	7.61
12	M3-I3	1.90	16	7.45
13	M4-I4	2.07	15	7.34

The sieve analysis results of different soil blends are summarized in Table 4.6. The coefficient of uniformity (Cu) values show clear variations across the blends. The original soil recorded a Cu of 1.34, with M1 to M4 ranging between 1.44 and 1.54, indicating slight improvements. The isolated blends I1 to I4 had lower values, between 1.24 and 1.38, reflecting weaker gradation. However, the combined blends (M1I1 to M4I4) demonstrated significant enhancement, with values ranging from 1.90 to 2.07, the highest being M4I4. Overall, the combined blends achieved better gradation characteristics compared to individual modifications or isolated blends. The Coefficient of Uniformity (Cu) of the original soil is 1.34, indicating a relatively uniform particle size distribution. The addition of material marble dust (M1–M4) slightly increases Cu, while material iron powder (I1–I4) shows varied Cu values depending on the blend, reflecting differences in particle size gradation.

The data for the blends shows distinct variations in values. The original soil recorded 43, while the modified blends M1 to M4 ranged between 30 and

27, showing lower values compared to the original. The isolated blends I1 to I4 had higher fluctuations, with I1 at 56, I2 at 31, I3 peaking at 90, and I4 at 38. The combined blends (M1I1 to M4I4) showed the lowest values overall, ranging from 22 to 15. In summary, isolated blends—especially I3—demonstrated the strongest performance, while the combined blends consistently recorded the lowest values.

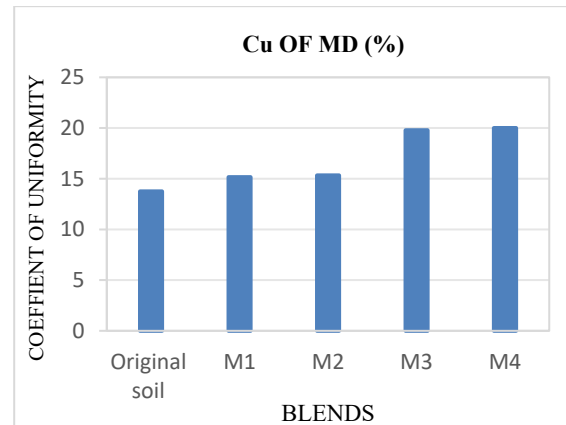


Fig -20: Coefficient of Uniformity (Cu) Variation in different blends of MD

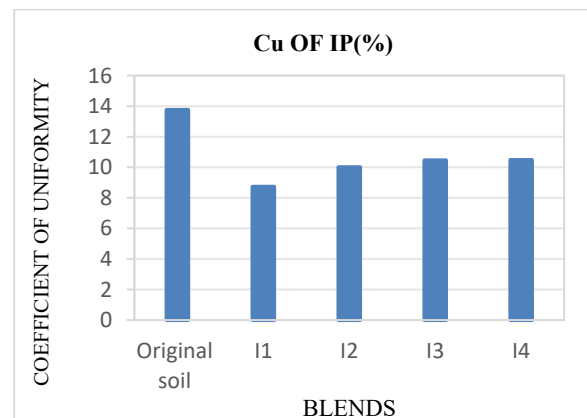


Fig -21: Coefficient of Uniformity (Cu) Variation in different blends of IP.

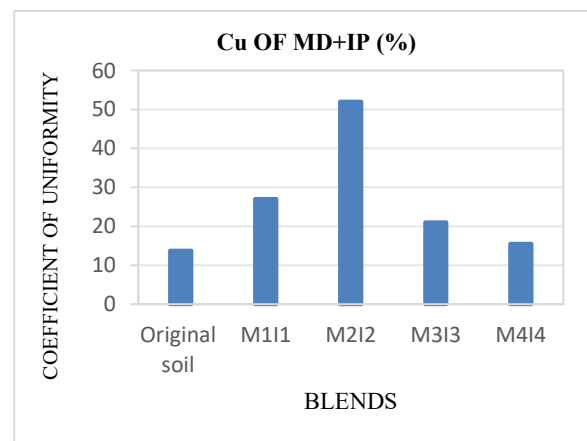


Fig -22: Coefficient of Uniformity (Cu) Variation in different blends of MD+IP .

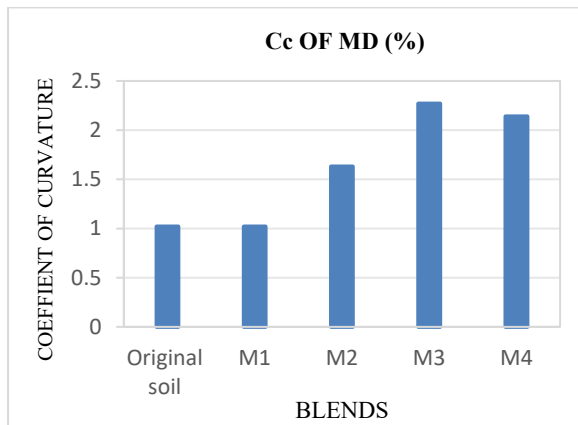


Fig -23: Coefficient of curvature(Cc) Variation in different blends of MD

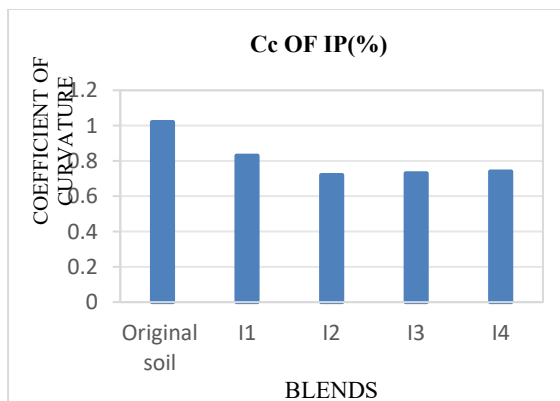


Fig -24: Coefficient of curvature(Cc) Variation in different blends of IP

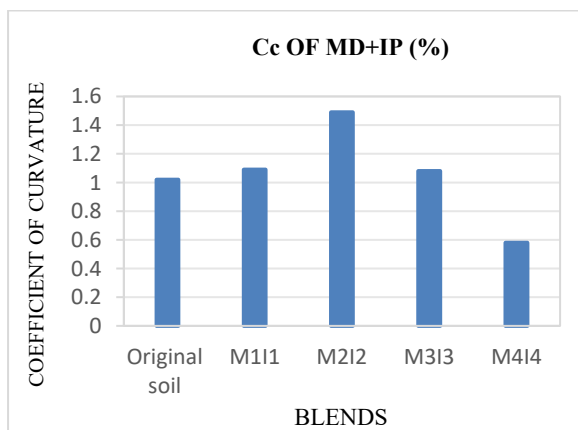


Fig -25: Coefficient of curvature(Cc) Variation in different blends of MD+IP.

The values for the blends show a gradual variation across different samples. The original soil recorded 5.71, while the modified blends M1 to M4 ranged from 5.93 to 7.75, showing steady improvement. The isolated blends I1 to I4 had higher values overall, with I3 reaching the maximum at 8.51. The combined blends (M1I1 to M4I4) maintained values between 7.34 and 7.66, reflecting balanced

performance. Overall, the isolated blends—especially I3—demonstrated the strongest enhancement compared to the original soil and other modifications. Meanwhile, the moderate values of the combined blends suggest that synergy between marble and iron powder does not always lead to superior outcomes. This finding highlights the need for careful optimization of blend ratios to achieve desired soil performance. The gradual improvement from M1 to M4 shows that incremental addition of marble powder steadily contributes to soil stabilization. On the other hand, the isolated blends reveal that iron powder has a more immediate and significant impact. These variations underline the importance of comparing different stabilization approaches to identify the most effective solution. Overall, the data confirms that industrial waste materials can be successfully utilized to enhance black cotton soil properties, with isolated iron powder blends showing the greatest promise.

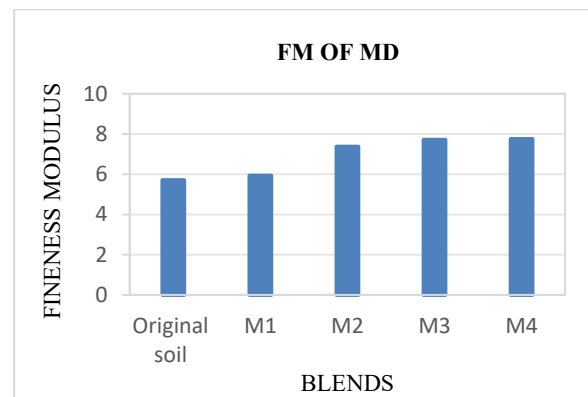


Fig -26: Fineness modulus Variation in different blends of MD

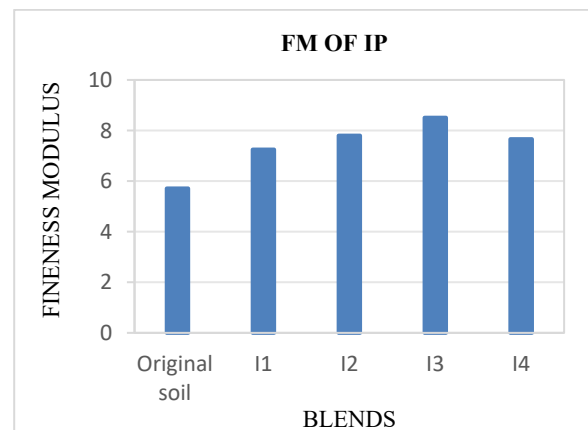


Fig -27: Fineness modulus Variation in different blends of IP.

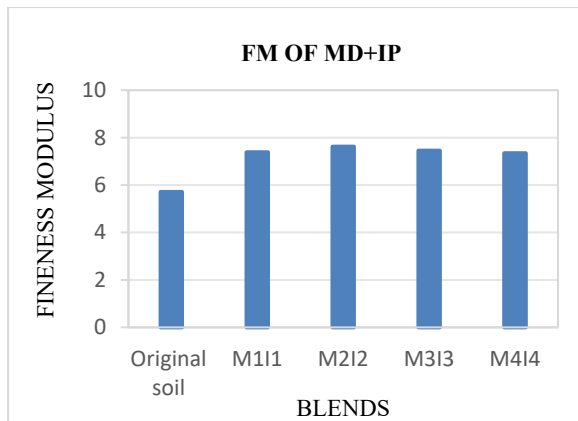


Fig -28: Fineness modulus Variation in different blends of MD+IP .

The Coefficient of Curvature (Cc) ranges from 15 to 90, showing that some blends have well-graded particles while others are poorly graded. The Fineness Modulus (FM) increases with most marble dust and iron powder blends compared to the original soil, indicating coarser material in the mixture. Combined blends (M-I) demonstrate intermediate values for Cu, Cc, and FM, suggesting that blending moderates particle size distribution and grading. Overall, these results indicate that blending stabilizing materials effectively modifies soil gradation, improving particle packing, uniformity, and potentially enhancing compaction and engineering performance.

4.6 Variation of Maximum Dry Density (MDD) and Optimum Moisture Content (OMC) with Different Blends.

Table-8: Results of Variation of Maximum Dry Density (MDD) and Optimum Moisture Content (OMC) with Different Blends.

Sr. No.	Blend Type	MDD (g/cc)	OMC (%)
1	Original Soil	1.34	43
2	M1	1.44	30
3	M2	1.54	34
4	M3	1.51	27
5	M4	1.49	25
6	I1	1.24	56
7	I2	1.33	31
8	I3	1.36	90
9	I4	1.38	38

10	M1-I1	1.92	22
11	M2-I2	1.95	18
12	M3-I3	1.90	16
13	M4-I4	2.07	15

The compaction characteristics of different soil blends are summarized in Table 4.6. The Maximum Dry Density (MDD) of the original soil is 1.34 g/cc with an Optimum Moisture Content (OMC) of 43%. Addition of material marble dust (M1-M4) increases the MDD slightly, while reducing the OMC, indicating improved compaction efficiency due to better particle packing. Material iron powder (I1-I4) generally exhibits lower MDD values, with higher OMC for some blends (e.g., 90% for I3), suggesting that these blends require more water to reach maximum density due to the presence of fine particles or moisture-retaining components. The combined blends (M-I) achieve higher MDD values (up to 2.07 g/cc for M4-I4) with lower OMC, indicating that the mixture of marble dust and iron powder results in more compact and stable soil, suitable for engineering applications.

The data shows that the original soil has a Maximum Dry Density (MDD) of 1.34 g/cc. All modifications (M1-M4) increased this density, with Sample M2 achieving the peak performance at 1.54 g/cc.

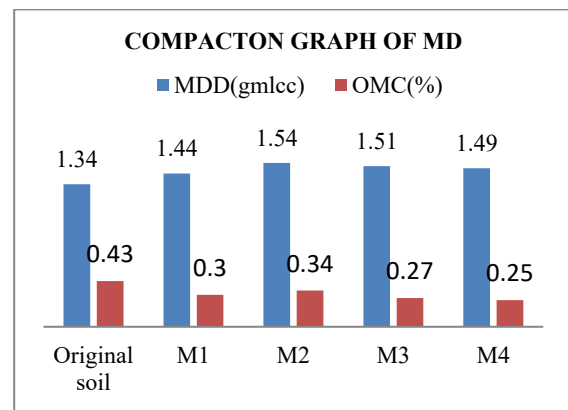


Fig -29: Comparative Analysis of MDD & OMC of MD with different blends.

This represents an approximate 15% increase in density compared to the original soil. Following M2, the density shows a slight downward trend, with M3 and M4 recording values of 1.51 g/cc and 1.49 g/cc, respectively. Regarding moisture, the original soil requires the most water with an Optimum Moisture Content (OMC) of 0.43%. Every modification significantly reduced the water needed for peak compaction, with M4 reaching the lowest OMC at 0.25%. Overall, the modifications improved the soil's engineering properties by making it denser and less moisture-dependent, with M2 identified as the

most effective modification for achieving maximum compaction.

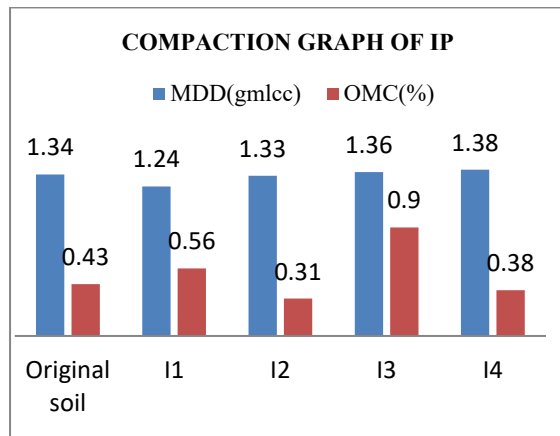


Fig -30: Comparative Analysis of MDD & OMC of IP with different blends.

Upon modification, sample I1 initially shows a decrease in likely due to a change in particle arrangement that increased the moisture requirement to However, a consistent improvement is observed from samples I2 through I4, with I4 ultimately achieving the highest density of at a relatively low moisture content of Notably, sample I3 exhibited the highest water affinity, peaking at an OMC of Overall, the data indicates that while initial modifications may disrupt soil packing, higher modification levels (specifically I4) successfully optimize the soil's engineering properties by increasing its maximum dry density beyond its original state.

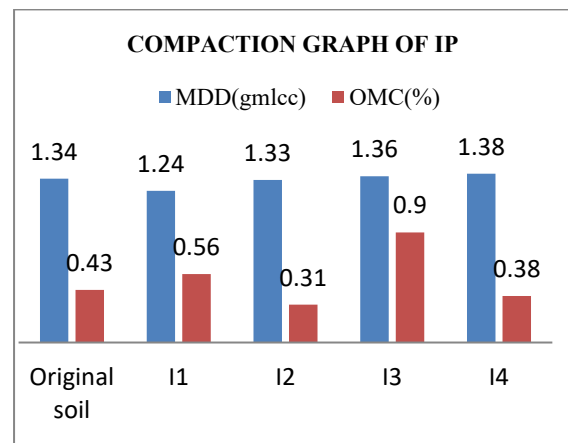


Fig -31: Comparative Analysis of MDD & OMC of MD+IP with different blends

The original soil starts with a Maximum Dry Density (MDD) of and an Optimum Moisture Content (OMC) of Following the combined modifications (M1I1 through M4I4), there is a steady and substantial increase in density alongside a consistent drop in moisture requirements. The MDD rises from at M1I1 to a peak of at M4I4, which represents a massive increase over the

original soil. Simultaneously, the water needed for peak compaction is more than halved, reaching a minimum of in the M4I4 sample. This indicates that the combined additive (MD+IP) is exceptionally beyond its original state.

5.CONCLUSION

The laboratory investigation on black cotton soil demonstrates that the untreated soil is stiff, low in permeability, highly compressible, and possesses low bearing capacity. Soil modification with industrial additives, particularly MD (Marble Dust) and IP (Iron Powder), significantly improves its geotechnical properties.

- Specific Gravity:** Increases with additive content, reaching maximum values at 20%, with IP showing the highest, MD the lowest, and the combination an intermediate effect.
- Liquid Limit:** MD at 20% is most effective in reducing the liquid limit to 18%, decreasing the soil's moisture affinity and enhancing stability.
- Shrinkage Limit:** 20% IP yields the lowest shrinkage limit (~5%), indicating reduced potential for volume change and cracking.
- Plastic Limit:** 20% IP significantly reduces plasticity (~10%), lowering moisture sensitivity.
- Maximum Dry Density:** Sample M2 (MD 20%) achieves the highest MDD (1.58 g/cc) with a low moisture requirement (0.34%), while Sample I4 (IP 20%) reaches 1.38 g/cc at 0.38% moisture. The combined modification M4I4 shows optimal performance, achieving the highest peak density (2.07 g/cc) with the lowest moisture requirement (0.15%).

Overall, soil modification using 20% MD, 20% IP, or their combination effectively improves the strength, density, and volume stability of black cotton soil, making it suitable for construction applications such as road subgrades and foundation layers. The results confirm that using locally available industrial waste can be a cost-effective and environmentally sustainable method to enhance the engineering properties of problematic soils.

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BIOGRAPH

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