Effect of Disintegration Times of the Homogeneity of Soil prior to Treatment

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Abstract: This paper presents an experimental study to investigate the effect of various disintegration times on the homogeneity of pre-treated natural soil before mixing with cementitious binders. Various disintegration times were applied, ranging from 10 s to 120 s. Four different soils were used with different characteristics from high, medium and low plasticity properties. Visual and sieving assessment were used to evaluate the best disintegration times to allow for a uniform distribution of water content and small-sized particles that would produce a uniform distribution of the binder around the soil particles. Results showed that a proper mixing time to homogenize and disintegrate the soil prior to treatment depended on several factors: soil type, water content and plasticity properties. For high plasticity soil, the disintegration time should be kept as short as possible. Increasing the disintegration time has negative effects on the uniformity of distribution of the binder around soil particles. The homogenizing and disintegration time were less important for low plasticity soils with low water content than for medium to high plasticity soils. The findings could assist various construction projects that deal with soil improvement through preparation of soil before adding a cementitious binder to ensure uniformity of distribution of the binder around soil particles and obtain uniform soil–binder mixtures.

Keywords: soil; homogeniz; disaggregate; prior to treatment; time

1. Introduction

Soil stabilization through addition of a hydraulic binder is used extensively to improve physical and mechanical properties of soft soils to achieve desired strength properties. Additives like cement and lime are typically used as stabilizers. More recently, industrial by-products, such as fly ash, cement kiln dust, blast furnace slags and other slags have been used. The chemical reaction between the soil and the stabilizer alters the physical and engineering properties of the soil and thus the desired strength and durability are obtained. For soil stabilization application and during the design process, a laboratory investigation is conducted first to obtain the enhancement in soil strength and stiffness. Usually, the specimens of the soil–binder mixture are prepared in a laboratory according to a standard procedure, which in principle should simulate the field conditions. These procedures vary between different countries; in addition, there are variations between different testing companies [1–6]. For instance, in Sweden, the specimens of soil–binder mixture are prepared according to the common procedure described by the Swedish geotechnical society report [4] and the design guide for soft soil stabilization [3]. In Japan, the specimens are prepared according to the Japanese geotechnical society standard [7,8]. These variations are related to differences in the soil type, type and procedure of soil stabilization in the field and the differences in traditional laboratory testing in general [5]. The uniform distribution of binder around soil particles represents the most common concern for obtaining a
uniform soil binder mixture. Disaggregating the natural soil prior to treatment has many effects such as homogenizing the soil, reducing the variation in water content and obtaining smaller chunks by separating the agglomerated particles. This process could assist in obtaining a uniform distribution for the cementitious binders around soil particles. Table 1 summarizes the most common procedures used to homogenize natural soil prior to treatment. The most common step in all procedures is that the natural soil has to be disaggregated and homogenized before adding the stabilizer. However, it is noticeable that most of the standards do not specify the required time for the disintegration and homogenization process [3–5,9,10]. Consequently, there is little knowledge regarding the time required to disaggregate and homogenize the soil before treatment with a cementitious binder. For these reasons, an experimental program was initiated in this study to determine the effects of various disaggregation times on the uniformity and homogeneity of soil.

Table 1. Most common procedures for homogenizing natural soil prior to treatment.

| Preparation Standards and Reference | Natural Soil Homogenization Method | Mixer Type |
|------------------------------------|-----------------------------------|------------|
| Tokyo Institute of Technology, Japan [11] | Soil is homogenized by mixing with its initial water content. | Domestic dough mixer with a 5000 to 30,000 cm³ mixing bowl |
| Sapienza University of Rome, Italy [12–14] | The soil is homogenized by remixing alone. Water is added at this stage to adjust the soil water content. | Hobart mixer |
| University of Coimbra, Portugal [15] | The soil is homogenized by re-mixing with a mixing speed of 136 rpm. To readjust the soil water content, water is added to the soil as a slurry of water and binder mixture. | Hobart mixer (model N50) |
| Swedish Geotechnical Society (SGS) [4,16] | The soil is first homogenized thoroughly by mixing the soil alone. The soil is homogenized by stirred it using a mixer. The soil water content is adjusted by adding water. | Dough mixer or kitchen mixer with sufficient capacity and rpm |
| Japanese Geotechnical Society (JGS) [7,8] | The soil is mixed until becoming visually homogenous. | Domestic dough mixer with a 5000 to 30,000 cm³ mixing bowl |
| [3] | Mixing the conglomerate of soil thoroughly for three to four minutes. | Dough mixer or kitchen mixer with sufficient capacity and rpm |
| [17] | Homogenizing the soil by mixing it alone for two to six minutes. It normally takes place the day before the stabilizer is added. Soil is air-dried for 24 hours and mixed with dry binder for one minute or until the mixture homogenized visually. Mixing the soil for approximately three minutes at the lowest setting of the mixer (approximate rotation of the mixing tool of 100 to 175 cycles/min). Water is added to adjust the soil water content. The soil in the field corrected to the particle size distribution before adding the binder by blending the soil alone to break up large blocks or boulders. | Kitchen mixer with sufficient capacity |
| ASTM [20–22] | Mechanical mixer, capable of producing uniform and homogeneous mixtures |
| Federal Highway Administration [10] | The sample is disintegrated or homogenized for several minutes. | Dough mixer or kitchen mixer with sufficient capacity and rpm |
| European standard [23] | Mixing the untreated soil alone either by mechanical mixer or by hand. | Mixer with enough capacity |
| French standard [24,25] | Kitchen mixer with sufficient capacity |
| British standard [26] | | |

2. Materials and Methodology

2.1. Materials

Four different types of soil were used in this study. The soils were chosen to be of different character and locations. Soil 1 was excavated from Gothenburg, south west coast of Sweden. Soil 2 and 3 were excavated from different depths in Sunderbyn area in Luleå, the northernmost part of Sweden.
Soil 4 was excavated from Umeå, in the north east part of Sweden. The soils were classified by tests of particle size distribution, consistency limits, loss of ignition, chemical composition, pH and specific gravity. The physical and mechanical properties are presented in Table 2. The chemical composition of the tested soils was obtained in a certified laboratory as listed in Table 3. The particle size distribution of the tested soil is shown in Figure 1. The soils were classified according to the Swedish standard. Organic content showed that organic content ranged from 2.7% to 6.8%. The soils were classified as having low to medium organic content [27,28].

![Particle size distribution of four soils type.](image)

**Figure 1.** Particle size distribution of four soils type.

**Table 2.** Engineering properties of the four soil types.

| Parameters       | Soil 1          | Soil 2          | Soil 3          | Soil 4          |
|------------------|-----------------|-----------------|-----------------|-----------------|
| Soil location    | Gothenburg      | Sunderbyn, Luleå| Umeå            |
| Depth, m         | Aerobic (N)     | Aerobic         | Aerobic         | Aerobic         |
| Particle-size distribution (%)* | 1–2             | 1.8–2           | 0.3–0.4         | 2.7–4           |
| Fine sand (%)    | 29              | 4               | 15              | 10              |
| Silt (%)         | 55              | 67              | 64              | 80              |
| Clay (%)         | 16              | 29              | 21              | 10              |
| Consistency limits (%)** | 37              | 95              | 48              | 45              |
| Liquid limit (%)* | 20              | 37              | 32              | 35              |
| Plasticity limit (%)** | 18              | 58              | 16              | 10              |
| Natural water content (%) | 27–30           | 50              | 43–45           | 40–50           |
| Particle density | 2.69            | 2.69            | 2.67            | 2.71            |
| Loss of ignition %*** | 4.1             | 7               | 4.8             | 2.8             |
| Bulk density (g/cm³) | 1.51            | 1.73            | 1.76            |                |
| pH               | 5               | 7               | 4.6             | 6.4             |
| Soil Classification | Sandy clayey silt | Silty clay    | Silty clay      | Silt            |

* Determined by the fall cone test according to Swedish standards [29]. ** Determined according to Swedish standards [30]. *** Determined according to Swedish standards [31]. **** Determined according to Swedish standards [32,33].
were prepared. The first specimen was prepared directly after mixing of soil and evaluated. While the mixing times were increased in several steps from 6 to 120 s for various soil types, to investigate the behavior of soil particles. The disintegration times were chosen depending on the soil type, plasticity index and water content.

Disintegration of the soils was achieved by using a laboratory mixer with mixing speed of 107 rpm. Disintegration time (T) is defined as the time required to homogenize and separate the agglomerated soil particles into smaller sizes, which represents the mixing duration in seconds. The disintegration (mixing) times were increased in several steps from 6 to 120 s for various soil types, to investigate the behavior of soil particles. The disintegration times were chosen depending on the soil type, plasticity index and water content.

After mixing the soil with its natural water content for a specified time (Table 4), two specimens were prepared. The first specimen was prepared directly after mixing of soil and evaluated. While the second specimen was left to air dry at a controlled room temperature of about 20 °C for two days and evaluated. The air-dried specimen was prepared in order to avoid any concerns about clogging of sieve openings due to the wet specimen’s moisture content.

| Specimen Type       | Disintegration Time (T) (Second) | Number of Samples | Sieving Time (Minutes) |
|---------------------|----------------------------------|-------------------|------------------------|
| Wet                 | 0 10 16 30 45 60 75 90 120       | 15                | 10 15 30 50 60         |
| Air dry             | 17 30 60                         | 4                 |                        |
| Wet                 | 0 10 13 16                       | 8                 |                        |
| Air dry             | 10 13                            |                   |                        |
| Wet                 | 0 6 12 22                        | 8                 |                        |
| Air dry             | 6 13                             | 4                 |                        |
| Wet                 | 0 7 15 30                        | 10                |                        |
| Air dry             | 15 30                            | 4                 |                        |

A visual observation and standard dry sieving tests using a sieving machine were used to optimize the ideal (proper) disintegration time for wet and air-dried specimens based on obtaining a smaller size of soil particles. The sieves used ranged in size from 16 to 0.063 mm. To find a suitable sieving time, six wet soil specimens from Soil 3 were prepared and sieved at different sieving times from 10 to 60 mins (Figure 2).

| Table 3. Chemical composition of tested soils. |
|----------------------------------------------|
| Soil location | Gothenburg | Sunderbyn, Luleå | Umeå |
| Soil conditions | Aerobic | Anaerobic (N) | Aerobic | Anaerobic |
| Silicon oxide (SiO2) % | 65.7 | 54.7 | 54.1 | 63.3 |
| Aluminum oxide (Al2O3) % | 12.3 | 12.8 | 11.3 | 10.8 |
| Calcium oxide (CaO) % | 2.4 | 2.11 | 1.88 | 1.9 |
| Iron oxide (Fe2O3) | 3.42 | 4.33 | 4.93 | 3.7 |
| Potassium oxide (K2O) % | 2.84 | 2.77 | 2.67 | 2.29 |
| Magnesium oxide (MgO) % | 1.31 | 2.25 | 1.4 | 1.29 |
| MnO % | 0.15 | 0.217 | 0.0482 | 0.0644 |
| Sodium oxide (Na2O) % | 0.55 | 2.56 | 2.68 | 2.47 |
| P2O5 % | 0.15 | 0.182 | 0.16 | 0.176 |
| TiO2 % | 0.55 | 0.677 | 0.615 | 0.603 |
| Sulfate content, mg/kg TS | 24800 | 3400 | 2800 | |

2.2. Testing Program

A visual observation and standard dry sieving tests using a sieving machine were used to optimize the ideal (proper) disintegration time for wet and air-dried specimens based on obtaining a smaller size of soil particles. The sieves used ranged in size from 16 to 0.063 mm. To find a suitable sieving time, six wet soil specimens from Soil 3 were prepared and sieved at different sieving times from 10 to 60 mins (Figure 2).

Figure 2. Laboratory mixer and sieving test for wet soil specimen.
3. Results

3.1. Visual Evaluation

The purpose of the visual evaluation was to show how soil particles can be affected by increased disintegration time. For this reason, only a few samples were chosen to illustrate the effects.

Figure 3 shows the visual evaluation of Soil 1 before and after disintegration at various times. Figure 3a shows that the soil specimen consisted of different sizes of agglomerated particles, ranging from a few millimeters to 8 cm. After homogenizing the soil specimen at 16 and 17 s disintegration times, it was found that the soil started to develop small-sized particles due to the breaking up of the agglomerated particles, as shown in Figure 3b,c for wet and air-dried specimens, respectively. When the disintegration time was increased to 30 s, it was seen that soil particles started to agglomerate and adhere to each other, forming larger agglomerated particles, as shown in Figure 3d,e for both wet and air-dried specimens. A similar observation was made regarding the formation of larger sizes of agglomerated particles when the disintegration time was increased to 60 s (Figure 3f,g) until the soil became almost one piece at a 120 s disintegration time.

![Visual evaluation of Soil 1 before and after disintegration at various times: (a) Non homogenized soil specimen; (b) Wet soil specimen prepared at 16 seconds; (c) Air dried soil specimen prepared at 17 seconds; (d) Wet soil specimen prepared at 30 seconds; (e) Air dried soil specimen prepared at 30 seconds; (f) Wet soil specimen prepared at 60 seconds; (g) Air dried soil specimen prepared at 60 seconds.](image-url)

Figure 3.
Figure 4 shows the visual assessment of Soil 2 before and after disintegration at various times. It can be seen in Figure 4a that the soil specimen contained a wide range of agglomerated particles from 1 to 9 cm in size. After homogenizing the soil specimen at disintegration times of 10 and 13 s, it was found that the agglomerated particles in the soil started to break up into small-sized particles, as shown in Figure 4b,c. However, when the disintegration time was increased to 16 s, the soil particles started to agglomerate and adhere to each other and became stickier, as shown in Figure 4d.

Figure 5 shows the visual evaluation of Soil 3 before and after disintegration at various time periods. Figure 5a shows that the original soil specimen consisted of a wide range of agglomerated particles ranging from a few millimeters to about seven centimeters. After homogenizing the soil at 6 and 13 s disintegration times, the agglomerated soil particles started to break into small-sized particles, as shown in Figure 5b–d for both wet and air-dried specimens. Subsequently, when the disintegration time was increased up to 25 s, the soil particles started to agglomerate and adhere to each other until they became almost one piece of soil, as shown in Figure 5e.
Figure 5. Visual evaluation of Soil 3 before and after disintegration at various times: (a) Non homogenized soil specimen; (b) Wet soil specimen prepared at 13 seconds; (c) Air dried soil specimen prepared at 6 seconds; (d) Air dried soil specimen prepared at 13 seconds; (e) Wet soil specimen prepared at 25 seconds.

Figure 6 shows the visual evaluation of Soil 4 before and after disintegration at various times. Figure 6a show that the specimen consisted of a wide range of agglomerated particles, ranging from a few millimeters to 8 cm. After homogenizing the soil specimen with a 15-s disintegration time, it was found that the agglomerated soil particles started to break up into small-sized particles, as shown in Figure 6b,c for both wet and air-dried specimens, respectively. When the disintegration time was increased to 30 s, the soil particles started to agglomerate and adhere to each other until they became almost one piece, as shown in Figure 6d,e respectively.
Figure 6. Visual evaluation of Soil 4 before and after disintegration at various times: (a) Non homogenized soil specimen; (b) Wet soil specimen prepared at 15 seconds; (c) Air dried soil specimen prepared at 15 seconds; (d) Wet soil specimen prepared at 30 seconds; (e) Air dried soil specimen prepared at 30 seconds.

3.2. Dry Sieve Tests

3.2.1. Sieving Time

Figure 7 shows the effect of various sieving times on the percentage passing through the sieve for six wet specimens from Soil 1 prepared at 20 s disintegration time. The percentage of passing was expressed in terms of percentage of the total weight of soil that passed through different sieves. It can be seen there is no additional effect after 15 min of sieving. Therefore, 15 min sieving time was used for all the soil specimens.
3.1.1. Proper (Ideal) Disintegration Time

Figures 8 and 9 present the percentage passing through versus sieve sizes for wet and air-dried specimens, respectively of soil 1 prepared at different disintegration times. From Figure 8, the passing percentage for the original soil specimen (without any mixing) was 63% with a 16 mm sieve. After homogenizing the soil specimen at 10 and 16 s disintegration times, it was found that the soil started to have smaller-sized particles, through the breakup of agglomerate particles. The percentage passing through a 16 mm sieve size was significantly increased up to 93% and 100% respectively (Figure 8). This also applied to other sizes of sieve. When the disintegration time increased up to 30 s, it was seen that soil particles started to agglomerate and adhere to each other to form bigger sizes of agglomerated particles. The percentage passing through decreased compared to 10 and 16 s for all sizes of sieve. The percentage passing through was higher compared to the original soil specimen. A similar observation was made with larger sizes of agglomerated particles found when the disintegration time was increased up to 60 s until it became almost like one piece of soil at 120 s disintegration time. The percentage passing through decreased compared to the original soil specimen for all sizes of sieve.

Figure 7. Percentage passing through versus sieve size for wet Soil 1 specimen sieved at various times.

3.2.2. Proper (Ideal) Disintegration Time

Figures 8 and 9 present the percentage passing through versus sieve sizes for wet and air-dried specimens, respectively of soil 1 prepared at different disintegration times. From Figure 8, the passing percentage for the original soil specimen (without any mixing) was 63% with a 16 mm sieve. After homogenizing the soil specimen at 10 and 16 s disintegration times, it was found that the soil started to have smaller-sized particles, through the breakup of agglomerate particles. The percentage passing through a 16 mm sieve size was significantly increased up to 93% and 100% respectively (Figure 8). This also applied to other sizes of sieve. When the disintegration time increased up to 30 s, it was seen that soil particles started to agglomerate and adhere to each other to form bigger sizes of agglomerated particles. The percentage passing through decreased compared to 10 and 16 s for all sizes of sieve. The percentage passing through was higher compared to the original soil specimen. A similar observation was made with larger sizes of agglomerated particles found when the disintegration time was increased up to 60 s until it became almost like one piece of soil at 120 s disintegration time. The percentage passing through decreased compared to the original soil specimen for all sizes of sieve.
Figure 8. Percentage passing through versus sieve size for wet specimens of Soil 1 prepared at different disintegration times.

For the air-dried specimens, Figure 9 shows that the percentages passing through a 16 mm sieve were 98%, 20% and 10% after 17, 30 and 60 s of disintegration time respectively.

Figure 9. Percentage passing through versus sieve size for air-dried specimens of Soil 1 prepared at different disintegration times.

For the air-dried specimens, Figure 9 shows that the percentages passing through a 16 mm sieve were 98%, 20% and 10% after 17, 30 and 60 s of disintegration time respectively.
Figure 10 shows the percentage passing through versus sieve sizes for wet and air-dried specimens of soil 2 prepared at different disintegration times. For the original soil specimen (without any mixing), it is seen that the pass percentage is 8% at 16 mm sieve size. After homogenizing the soil for 10 s of disintegration time, the passing through a 16 mm sieve size significantly increases up to 88% and 60% for air-dried and wet specimens, respectively. The pass percentage is also significantly increased for the other sizes of sieve. Then, when the disintegration time increases to 13 s, the passing percentage through a 16 mm sieve size is 75 and 33% for air-dried and wet specimens, respectively. With a further increase in disintegration time of up to 16 s, the pass percentage decreases for all sieve sizes to the same percentage as the original soil specimen without any preparation or mixing.

Figure 11 presents the pass percentage versus sieve sizes for wet and air-dried specimens of Soil 3 prepared at different disintegration times. For the original soil specimen (without any mixing), it was seen that the specimen consisted of a wide range of agglomerated particles from a few millimeters to about seven centimeters and the passing through a 16 mm sieve size was 50%. After homogenizing the soil at 6 s disintegration time the passing through percentage at 16 mm sieve size increased up to 57% and 85% for wet and air-dried specimens, respectively. Then, when the disintegration time increased to 12–13 s, the percentage of passing through a 16 mm sieve size increased to 80% and 73% for wet and air-dried specimens, respectively. The pass percentage also increased for the other sieve sizes. With further increasing in the disintegration time up to 22 s, the passing through percentage decreased for all sizes of sieve compared to the original soil specimen.
Figure 11. Percentage passing through versus sieve size for wet specimens prepared at different disintegration times for Soil 3.

For Soil 4, Figures 12 and 13 show the passing through percentage versus sieve size for wet and air-dried specimens, respectively prepared at different disintegration times and initial water contents. For the original soil specimen with 40% water content, it was seen that the passing through percentage was 75% at 16 mm sieve size. When the soil is disintegrated for 10–20 s, the passing through percentage increased in all sizes of sieve and became 90% and 86%, respectively at 16 mm sieve size.

For Soil 4 with 50% water content, it was seen that the soil started to disintegrate into small particles at 7 s, and the percentage of passing was 57% at the 16 mm sieve. When the disintegration time was increased to 17 and 30 s, the passing through percentage at 16 mm sieve size decreased to 44% and 40%, respectively for wet specimens. This also applied to other sizes of sieve. On the other hand, when the wet specimen was left to be air-dried, it was found that the percentage passing through at 16 mm sieve size significantly increased to 100% and 90% for 15 and 30 s disintegration time, respectively as shown in Figure 13.
4. Discussion

Soil 4 (Silt, Wc = 40% to 50%, PI=11%)
Wet specimens, sieving time: 15 minutes

- T=0 seconds, 40% Wc
- T=7 seconds, 50% Wc
- T=10 seconds, 40% Wc
- T=20 seconds, 40% Wc
- T=17 seconds, 50% Wc
- T=30 seconds, 50% Wc

Figure 12. Pass percentage versus sieve size for wet specimens of Soil 4 prepared at different disintegration times with different initial water contents.

Soil 4 (Silt, Wc = 50%, PI=11%)
Air-dried specimens, sieving time: 15 minutes

- T=15 seconds, 50% Wc
- T=30 seconds, 50% Wc

Figure 13. Pass percentage versus sieve size for air-dried specimens of Soil 4 prepared at different disintegration times.
4. Discussion

The preparation or mobilization of natural soil in order to mix it with a stabilizer can play an important role in obtaining a uniform soil–binder mixture. The methodology adopted to optimize a suitable disintegration time is based on two types of assessment. The first is a visual assessment, as noted above. The second assessment is based on improving the grain size distribution curves and obtaining smaller sized particles after the disintegration process. The median diameter ($D_{50}$) is considered in the evaluation. $D_{50}$ represents the diameter of soil particle (in mm) corresponding to 50% of the sample’s passing percentage, which splits the curve with half above and half below this diameter.

Soil 1 was classified as sandy clayey silt with medium plasticity. The soil water content was below the liquid limit. The median particle diameter ($D_{50}$) was 13 mm for the non-homogenized soil specimen (Figure 8). For the wet soil specimens, the $D_{50}$ decreased to 5.5, 4 and 9.5 mm after the soil was homogenized for 10, 16 and 30 s, respectively. When the disintegration time was increased in several steps up to 120 s, the $D_{50}$ was increased to 16 mm. For the air-dried specimens, the $D_{50}$ was about 3 mm after the soil was homogenized for a 17 s disintegration time (Figure 9). The passing percentage was almost the same for the wet and air-dried specimens at a low disintegration time (less than 17 s) and high for wet specimens compared to the air-dried specimens when the disintegration time was increased to 30 s. This can be related to the medium plasticity properties of the soil in addition to the water content being below the liquid limit of the soil. When the soil particles agglomerated and adhered together at a high disintegration time, it became difficult to break them up again during the sieving process and they tended to stick in the opening of the sieve. The ideal disintegration time for Soil 1 ranged between 10 and 20 s and should not exceed 30 s.

Soil 2 was classified as silty clay with high plasticity. The soil water content was almost half of the liquid limit. After the natural soil was homogenized for 10 s, the $D_{50}$ ranged between 11 and 7.5 mm for wet and air-dried specimens, respectively. When the disintegration time was increased to 13 s, the $D_{50}$ was increased to 10.5 mm for the air-dried specimens. The passing percentage for air-dried specimens was higher compared to the wet specimens at 10 and 13 s disintegration times. This could be ascribed to the high plasticity property of the soil, which made the wet soil particles adhere to each other and stick in the sieve openings. The proper disintegration time for Soil 2 ranged between 10 and 13 s and should not exceed 16 s.

Soil 3 was classified as silty clay with medium plasticity. The soil water content was at the liquid limit of the soil. The $D_{50}$ was 16 mm for the non-homogenized soil specimen. After the natural soil was homogenized for 6 s, the $D_{50}$ decreased to 10 and 14 mm for the air-dried and wet soil specimens, respectively. When the disintegration time was increased to 12–13 s, the $D_{50}$ ranged between 10 and 11 mm for the wet and air-dried soil specimens, respectively. The $D_{50}$ increased to 16 mm when the disintegration time was further increased to 22–25 s. At 6 seconds disintegration time, the passing percentage for the air-dried specimens was higher compared to the wet specimens. This can be explained by the wet soil sample becoming stuck in the sieve openings (and thus not passing to the next sieve) due to the high moisture content and medium plasticity properties of Soil 3. The proper disintegration time for Soil 3 ranged from 6 to 13 s and should not exceed 22 s.

Soil 4 was classified as silt with low plasticity. The initial water contents ($W_c$) of soil were chosen to be below ($W_c = 40\%$) and above ($W_c = 50\%$) the liquid limit of the soil in order to investigate the effect of different water contents on low plasticity soil after homogenization and with various disintegration times. The $D_{50}$ was 9 mm for the non-homogenized soil specimen with 40% water content (below the liquid limit of the soil). After the natural soil was homogenized for 10 to 20 s, the $D_{50}$ was decreased to 6 mm. Conversely, for the wet soil specimens with an initial soil water content above the liquid limit (50%), the $D_{50}$ was 16 mm after homogenized for 7 s disintegration time.

In contrast, the $D_{50}$ ranged between 6 and 7 mm for the air-dried specimens prepared at 15 and 30 s disintegration times, respectively and with an initial water content above the liquid limit. The passing percentage for the air-dried specimens was significantly higher compared to the wet specimens prepared with the same disintegration time and initial water content (50%), as shown in
Figures 12 and 13. Due to the low plasticity properties of Soil 4, the variation between the wet and air-dried specimens was related to the high-water content of the soil, which made the wet soil particles adhere to each other after disintegration and stick to the sieve openings. This clearly showed the effect of water content in low plasticity soil.

Therefore, the proper disintegration time for Soil 4 was mainly affected by the variation in the initial water content. When the water content was below the liquid limit of the soil, the appropriate disintegration time ranged between 15 s and a maximum of 30 s, while for soil with a high-water content (above the liquid limit) the disintegration time should be as low as possible and should not exceed 17 s.

The agglomeration of particles after the homogenizing process was explained by the increased interaction forces between particles, leading to the formation of clusters as a result of how the particles adhere to each other [34]. The following mechanisms can lead to a rise in the agglomeration of particles for various material types [35]:

- Mechanical interlocking: this mainly occurs if the material’s particles are long and thin in shape, leading to large masses becoming completely interlocked.
- Surface attraction: force between soil particles can increase the substantial bonds between particles. This effect is more pronounced in very fine particles (with less than 10-micrometre diameter) due to a high ratio of specific surface to unit volume.
- Plastic welding: this occurs due to the development of very high pressures on an extremely small surface area between irregular particles.
- Electrostatic attraction: the movement of the particles is caused by the electrostatic forces between particles.
- Effect of moisture: Moisture has the effect of raising the surface tension effects by collecting near points of contact between particles. It may also dissolve small sections of the particles and act as a bonding agent on subsequent evaporation.

A recent study reported that solid material–binder mixtures can be significantly affected by the chemical properties of the investigated solid material. For instance, the soluble salts and sulphate content can be a concerning issue regarding the efficacy of further mixing procedure with binder materials [36].

Visual and sieve analysis results indicate that, at a specified disintegration time, the soil started to have a small particle size when the agglomerated particles break into small-sized particles. Subsequently, when the disintegration time was increased, the soil particles started to adhere to each other and form clusters. This process continued until almost all the soil had accumulated into a single mass when the disintegration time was significantly increased. Table 5 summarizes the proper disintegration time to homogenize various soil types.

**Table 5.** A summary of the proper disintegration time for homogenizing different soil types.

| Soil Types       | Plasticity Index, PI% | Water Content % | Proper Disintegration Time (T), (Seconds) | D₅₀, mm |
|------------------|-----------------------|-----------------|-----------------------------------------|---------|
|                  |                       |                 | Between | Not Exceed |         |
| Soil 1 (sandy clayey silt) | 18                    | 27–30           | 10–20   | 30         | 4–5     |
| Soil 2 (silty clay)       | 58                    | 50              | 10–13   | 16         | 10.5    |
| Soil 3 (silty clay)       | 16                    | 47              | 6–13    | 25         | 10–11   |
| Soil 4 (silt)             | 11                    | 50              | 15–20   | 30         | 6.5     |
|                  |                       |                 | 7       | 17         | 10.5    |
5. Conclusions

The findings of this study demonstrate that the ideal time for the homogenization and disintegration of soil depends on several factors, such as soil type, water content and plasticity index. For high plasticity soil, the disintegration time should be kept as low as possible. The disintegration time for medium and low plasticity soils is mainly affected by the soil’s initial soil water content. Obviously, increasing the disintegration time has negative effects on the uniformity of distribution of the binder around soil particles. The homogenizing and disintegration time are less important for low plasticity soils with low water content than for medium to high plasticity soils.

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