Mechanics of Manufactured Soil Using Powder Wastes

Mécanique des sols fabriqués à partir de déchets de poudre

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ABSTRACT: Powder wastes like fly ash are produced in large volumes. They have handling, disposal problems and poor engineering performance due to their silt size. Manufacturing artificial sand and gravel from these silt sized powder wastes in large quantities will solve the associated problems of having silt size. Disc pelletizers with manufacturing capacities reaching one million ton a year makes this process economically feasible and practical for geotechnical applications. Fly ash is one of these powder wastes having silt size and easily available in many countries where they create huge disposal problems. Cold bonding pelletization technique is used to produce fly ash pellets of sand and gravel size and their mechanical properties are determined. The manufactured pellets are lightweight materials with adequate strength and can be used in many geotechnical projects. The fly ash pellets show similar behavior to that of calcareous sands. In addition to utilization of pellets as manufactured, it is also possible to manufacture soil to the desired specification by adding additives or apply surface treatment.

RÉSUMÉ : Déchets de poudre comme les cendres volantes sont produits en grandes quantités. Ils ont la manipulation, et l'élimination des problèmes de performance d'ingénierie pauvres en raison de leur taille limon. Fabrication de sable et de gravier artificielle à partir de déchets de limon ces poudres de taille en grandes quantités permettra de résoudre les problèmes associés ayant une taille de limon. Granulateurs à disques avec des capacités de production pour atteindre un million de tonnes par an rend ce processus économiquement faisable et pratique pour des applications géotechniques. Les cendres volantes sont un de ces déchets en poudre ayant une taille de limon et facilement disponible dans de nombreux pays où ils creat énormes problèmes d'élimination. Technique de granulation à froid de liaison est utilisé pour produire des boulettes de cendres volantes de sable et de gravier taille et leurs propriétés mécaniques sont déterminées. Les pellets sont fabriqués avec des matériaux légers résistance suffisante et peut être utilisé dans de nombreux projets en géotechnique. Les granulés de cendres volantes présentent un comportement similaire à celui des sables calcaires.

KEYWORDS: Powder wastes, cold bonding pelletisation, silt size, fly ash, calcerous sands, grain crushing.

1 INTRODUCTION

With increasing disposal costs, and growing ecological concerns, waste materials are utilized in geotechnical applications more and more each year. Due to its silt size, powder materials are hard to handle, transport, compact and dispose. Increasing the size of the powder wastes from silt size to sand and gravel size has a lot of benefits. Powder wastes like coal burning thermal power plant fly ash are used in many geotechnical applications. The pelletization cost for fly ash is around one to two Euros per ton and the capacity of one pelletizer can be as high as one million tons per year, making this approach a feasible and practical application in geotechnical engineering. Annual fly ash production for many countries is in the range of 1 to 100 million tons. This paper summarizes a series of research work about manufacturing sand and gravel from powder fly ash by cold bonding pelletization technique. The pelletization mechanism is explained and physical and engineering properties of the produced pellets are given.

The manufactured pellets behave like calcareous sands found in the nature. The source and shape difference of the natural calcareous sands do not exist in the manufactured pellets having nearly perfect sphericity and roundness. The crushing behavior of the manufactured soil is studied in detail. For potential applications like backfill for retaining walls, fill under the footings, pile installation in existing manufactured soil embankment, anchor installation in manufactured fills, the interface behavior and the influence of crushability on the interface behavior is also studied. Finally odometer tests, direct shear tests are conducted and the results are summarized.

1.1 *Mechanism of pellet formation*

Pelletization process is the agglomeration of moisturized fines in a rotating drum or disc. The product at the end of the process is called the "fresh pellet". The crushing strength of the fresh pellet must be enough for hauling and stockpiling purposes. The pelletization technology is widely used in powder metallurgy engineering, and medicine industry.

The pelletization theory was developed in 1940's. The performance of the pelletization process is a function of; i) the engineering properties of the material pelletized; ii) the amount of moisture in the medium; iii) the mechanical process parameters such as the angle of balling drum or disc to the normal and the revolution speed. Observations and analysis performed on these parameters with respect to mechanic and kinetic laws formed the theory of pelletization process (Baykal and Doven 2000).

When a fine grained material is moisturized, a thin liquid film forms on the surface of the grains, which forms meniscus between the grains. With the rotation in a balling drum or disc, they form ball shape structures with enhanced bonding forces between grains due to centrifugal and gravitational forces. The mechanism of pellet formation is presented in Figure 1. In the pendular state water is present only at point of contact of the grains. With more water addition some of the pores are filled with water in the funicular state. All intergranular space is filled with water in the capillary state. The most suitable state for pellet formation is the capillary state.

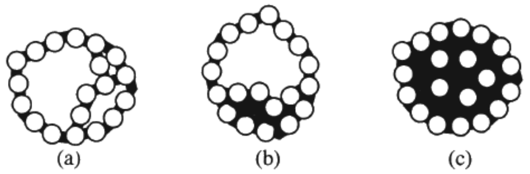

Figure 1. Mechanism of pellet formation; a) the pendular state; b) the funicular state; c) the capillary state.

The formation of capillary force between two grains is presented in Figure 2. The grain diameter of the powder material influences the magnitude of the surface tension force; small grain diameter is necessary to create enough pulling force to initiate agglomeration. Agglomeration can be achieved by drum or disc pelletizers. A typical disc pelletizer designed and manufactured for this study is presented in Figure 3 (Doven 1998).

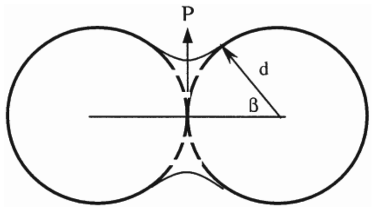

Figure 2.. Surface tension force created by water bridge between two particles.

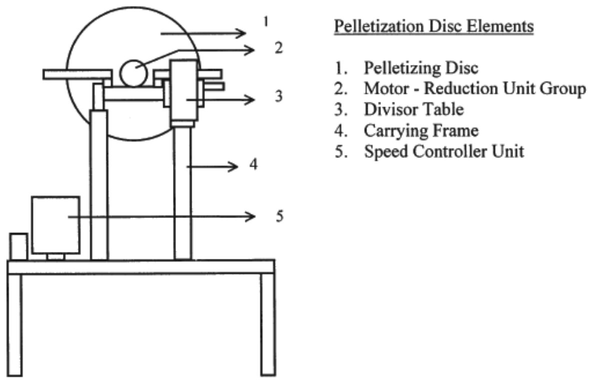

Figure 3. The sketch of disc pelletizer (back view).

The revolution speed of the disc can be controlled between 0 and 70 rpm and the angle of the disc plane to the normal can be adjusted between 0 and 90 degrees. The diameter of the disc is 0.40 meters and scraping blades are placed from center to one edge at 0.06 m intervals. During the revolution of the disc the grains pulled by surface tension are compacted further. The agglomerated grains hit to the scraping blades, falling free to the bottom section of the disc. This free fall action compacts the agglomerated product more. This repeated revolving and free fall action densifies and makes the agglomerated product stronger for handling. The motion of the grains in the disc is presented in Figure 4. The forces applied to the grains during pellet formation are presented in Figure 5. To achieve the most suitable pelletization process; the revolution speed and the angle of disc plane to the normal should be set in a manner to avoid the dominancy of gravitational or centrifugal forces (Figure 6).

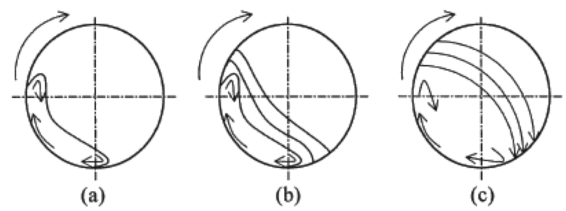

Figure 4. Motion of material in disc pelletizer revolving at various speeds.

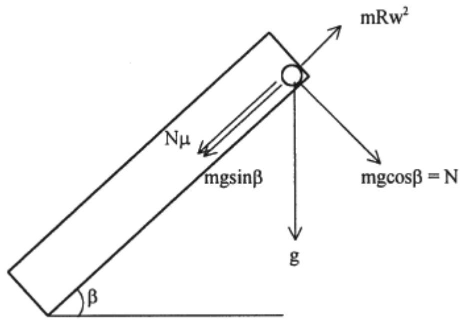

Figure 5. Forces acting on an individual pellet during pelletization process.

When the gravitational and centrifugal forces are in equilibrium then the normal force exerted by the pellet converges to zero and the following equation prevails.

$$m \times g \times \sin\beta = m \times R \times W^2 \qquad (1)$$

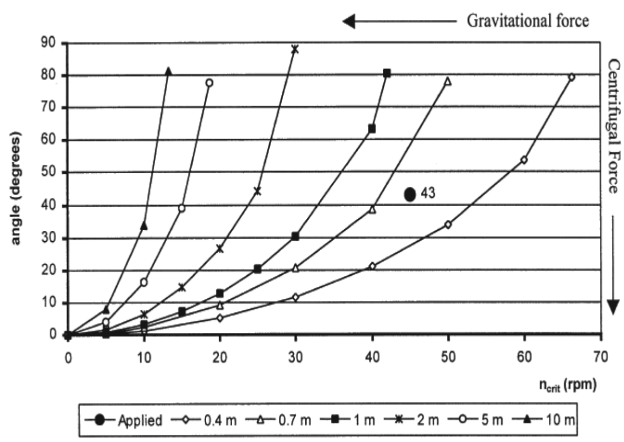

Figure 6. Variation of operation angle with respect to diameter of pelletization disc and critical revolution speed.

For various disc diameters the effect of operating angle and revolution speed on centrifugal and gravitational forces are presented in Figure 6.

2 PHYSICAL AND ENGINEERING PROPERTIES OF THE MANUFACTURED PELLETS

Turkey produces more than 17 million tons of fly ash annually. The fly ash used in the presented studies is obtained from Soma Coal Burning Thermal Power Plant in the west part of Turkey. The typical chemical composition of Soma fly ash is given in Table 1. The physical properties of manufactured fly ash pellets are presented in Table 2. The water absorption of the produced pellets is high.

Table 1. The chemical composition of Soma Fly Ash.

	Per cent
SiO_2	50.5
Al_2O_3	23.7
Fe_2O_3	5.8
CaO	9.3
MgO	2.6
SO_3	1.4
Loss on Ignition	2.2

Soma fly ash is self cementitious and it will harden without the need of another binder. The physical properties of the manufactured fly ash pellets are given in Table 2. The typical fly ash pellets are given in Figure 7.

Table 2. Physical properties of the fly ash pellets.

Unit weight	9.6 kN/m^3
Water absorption	31.4 %
Specific gravity	2.17
Bulk specific gravity	1.29

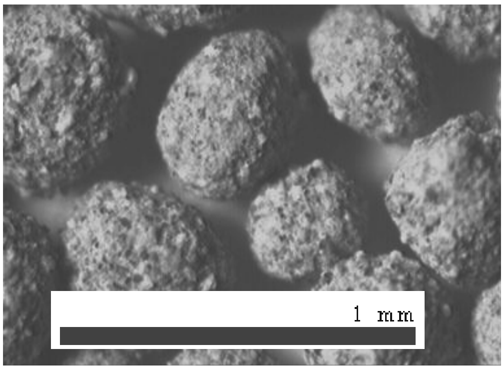

Figure 7. Manufactured fly ash pellets.

Table 3. Engineering properties of the fly ash pellets.

Optimum moisture content Dry unit weight (Standard Proct)	34.4 % 11.96 kN/m^3
Angle of internal friction	29.4°
California Bearing Ratio	58 %
Soundness loss of weight 9.5- 4.75 mm	9.0 %
Soundness loss of weight 19- 9.5 mm	7.9 %

Tables 1 through 3 show that fly ash pellets formed with cold bonding technique have similar engineering properties to that of soils. With no additional binder like lime or cement, self cementitious fly ash pellets have acceptable engineering properties. The soundness tests were conducted using sodium sulphate. Less than 12 percent weight loss after sodium sulphate treatment is allowable for concrete applications. The durability performance of the manufactured aggregates is adequate even for more demanding applications like concrete production.

From geotechnical point of view, the manufactured pellet aggregates have properties similar to those of granular soils except high water absorption value.

3 CRUSHING BEHAVIOR OF MANUFACTURED PELLETS

To demonstrate the effect of aggregate crushing sieve analyses were performed before and after direct shear testing of fly ash pellets at 50, 100 and 200 kPa normal stress. The change in grain size distributions before and after execution of the direct shear tests are given in Figure 8 (Danyıldız 2007).

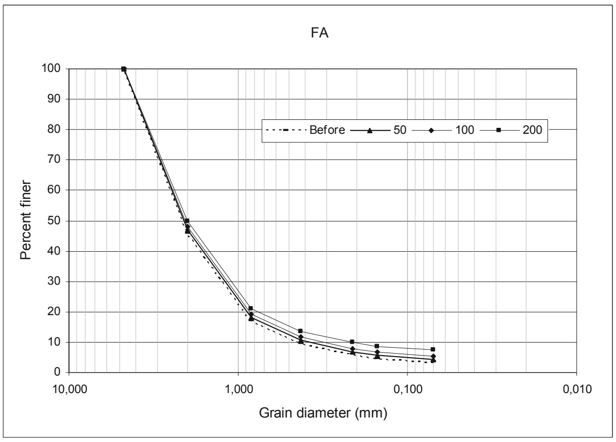

Figure 8. The grain size distribution of fly ash pellets before and after the conduction of direct shear test at a normal stress of 50, 100 and 200 kPa.

The fly ash pellets crushing behavior is similar to calcerous sands. The measured crushing behavior does not pose a threat for the engineering performance of the fly ash pellets for most geotechnical applications.

4 SHEAR STRENGTH OF FLY ASH PELLETS

Direct shear tests are conducted on manufactured fly ash pellet aggregates under 50,100 and 200 kPa normal stress applications. Interface tests are conducted on split samples of fly ash pellets and concrete. The internal friction angle and interface friction angle plots are presented in Figure 9.

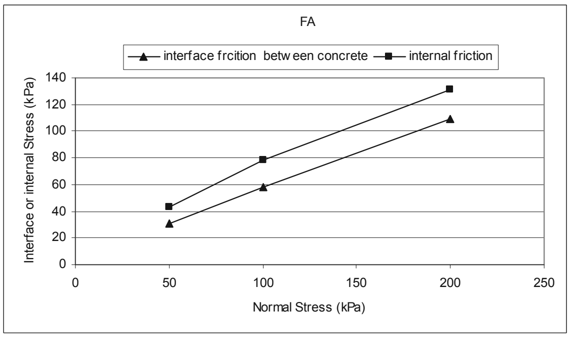

Figure 9. Internal and interface friction angles of fly ash pellets and pellet concrete interface.

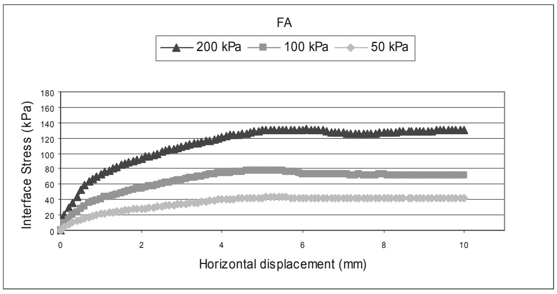

Figure 10. Shear stress vs. horizontal displacement of manufactured fly ash pellets.

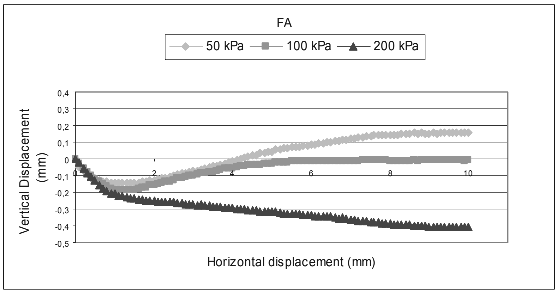

Figure 11. Shear stress vs. vertical displacement of manufactured fly ash pellets.

The shear stress vs. horizontal displacement and shear stress vs. vertical displacement values of fly ash pellet aggregates are presented in Figures 10 and 11 respectively. While dilation behavior is observed under 50 and 100 kPa, contraction behavior is seen under 200 kPa due to grain crushing.

5 SETTLEMENT BEHAVIOR OF PELLET AGGREGATES

Manufactured fly ash pellet aggregates are placed in an odometer and vertical stress of 25 to 1600 kPa is applied and removed. The corresponding void ratio values vs. the applied vertical stress are presented in Figure 12 (Erdurak 2011).

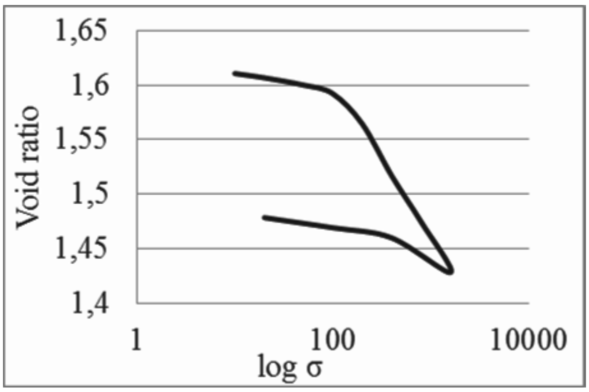

Figure 12. Odometer test results of fly ash pellets.

After the application of 100 kPa vertical stress the settlement increases. Even for high embankment fills the settlement magnitude is manageable.

6 CONCLUSIONS

The size of the silt sized powder wastes can be increased to sand and gravel size by pelletization technique in large volumes and low cost making the technique suitable for geotechnical applications. In this study experience with self cementing fly ash is presented, however the technique is applicable to other silt sized powder wastes provided that adequate capillary forces develop between the grains. For non self cementing fly ash, binders like hydrated lime or cement can be used for manufacturing. For higher performance needs the crushing strength of the fly ash pellets can be improved by using lime or cement additives. Surface treatment of pellets is possible using water glass at reasonable cost. High water absorbtion values(30 -35 per cent) place the manufactured granular material in an unique place in clasical soil classification. The durability of the aggregates is also satisfactory. With low unit weigh, free draining behavior, and ease of compaction, the manufactured soil has good potential for large volume utilization in geotechnical applications. The geotechnical properties of the manufactured soil ensures high stability. In addition to its potential for utilization in large volumes, the manufactured soil is a great tool for experimental research on crushable soils. It is possible to control the size, shape, surface texture, roundness, sphericity, crushing strength, unit weight, water absorption properties of the powder materials to produce soil with target engineering properties. This way by fixing one parameter at a time it will be possible to study the effects of each parameter on the engineering behaviour of natural soils. The cold bonding pelletization technology is a low tech technology which requires minimum capital investment and low operational costs. The whole process can be automated. If the manufactured aggregates are not used in a geotechnical application, a major reduction in disposal costs is achieved by improving handling, transportation, compaction and disposal in a dump site. Free draining property, high stability and potential for reuse when needed are other benefits of utilization.

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