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# A Modified Technique for Measuring Shrinkage of Clay Soils

M.I. TARIFUL, W.H. WAN SULAIMAN and D. AHMAD[1]
*Faculty of Agriculture*
*[1]Faculty of Engineering,*
*Universiti Putra Malaysia*
*43400 UPM, Serdang, Selangor, Malaysia*
*Fax: 603-9434419 Email: k275382@hotmail.com*

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## ABSTRAK

*Kaedah-kaedah D427 dan D4943 'The American Scociety of Testing and Material's untuk menentukan kecutan isipadu diubahsuai menggunakan pasir, suatu bahan yang tidak toksik untuk mengganti raksa dan lilin. Kaedah diubahsuai (pasir) dibandingkan dengan kaedah D427 (raksa) dan D4943 (lilin) dalam sukatan kecutan isipadu dan kecutan linear. Kaedah pasir memberi keputusan yang serupa dengan kaedah-kaedah raksa dan lilin untuk kecutan sampel-sampel tiga jenis tanah lempung yang diambil dari tiga paras kedalaman. Tiada perbezaan bererti terdapat pada ketiga-tiga kaedah untuk sukatan kecutan. Oleh itu, kaedah pasir merupakan suatu pilihan atau alternatif sesuai memandangkan ia kaedah yang mesra persekitaran, selamat dan lebih jimat berbanding dengan kaedah raksa dan kaedah lilin.*

## ABSTRACT

*The American Society for Testing and Materials D427 and D4943 methods for volumetric shrinkage were modified using sand, a non-toxic natural material, instead of mercury and wax respectively. The modified method (sand) was compared with the D427 (mercury) and D4943 (wax) methods for measuring volumetric and linear shrinkage. The sand method gave similar results as the mercury and wax methods for shrinkage of samples of three clay soils taken from three different depths. There was no significant difference between the three methods used to measure the shrinkage. Therefore the sand method is a useful alternative because it is environmentally friendly, safe and cheaper to use compared to the mercury and wax methods.*

## INTRODUCTION

In clay soils, changes in moisture content are accompanied by changes in volume. Swelling and shrinkage in clay soils have received much attention over the years (Haines 1923; Aitchinson and Holmes 1953; Berndt and Choughlan 1977; Bronswijk 1988). Shrinkage of clays by the loss of pore water during drying and their subsequent swelling during wetting are important phenomena for field water management. Volumetric shrinkage in soils is also an important physical parameter used in soil erosion and soil mechanics studies (Steven and Leonard 1990). Shrinkage and swelling of clays are also believed to play a major role in erosional processes producing soil pipes (Heede 1971).

There are several methods available for measuring shrinkage of soils. The American Society for Testing and Materials (ASTM) standardised D427 standard method for measuring shrinkage of soils specified the use of Hg for determining the volume displacement on oven-dried soil samples (ASTM 1974). The ASTM again standardised D4943 standard method for measuring shrinkage which specifies the use of wax, given the concern that mercury is a hazardous substance. This test method is an alternative to the Test Method D427, which was used to determine the shrinkage limit and other shrinkage factors of soils using mercury (ASTM 1989). The testing method D427 for assessing shrinkage was modified by substituting a less hazardous silicone-mineral spirits mixture for liquid

Hg (Steven and Leonard 1990). Mercury is highly toxic to body tissues and can readily be absorbed into the body by way of the respiratory and digestive systems as well as directly through the skin. On the other hand, wax is a melting material and hot wax can burn unprotected skin. Furthermore, over heated wax may burst into flames; therefore extreme care should be taken when working with hot wax.

Because of growing concerns over heavy metal toxicity in the environment and laboratory and in addition to the complexity of the methods for assessing soil shrinkage, modification of this method is imperative. Fine sand has less adsorption capacity and is fast moving, therefore, it may be employed instead of mercury and wax. Dasog and Shashidhara (1993) used dry fine sand for measuring crack volume of puddled rice soil. The present study also presents a modified approach by substituting dry fine sand for hazardous Hg and wax. It compares volumetric and linear shrinkage of clay soils measured using Hg and wax to those using fine sand for different layers of three clay soils of the Muda Agricultural Development Authority (MADA) rice area. It describes a simple technique for measuring and quantifying the volumetric shrinkage and linear shrinkage of soils by using fine sand instead of mercury and wax based on the ASTM D427 and D4943 standard methods. The investigation was undertaken with the objective of developing an alternative method for measuring shrinkage of soils which is not only environment friendly but also cheaper.

## MATERIALS AND METHODS

*Soils*

Three clay soils of the Muda rice irrigation area, namely, the Chengai, Tebengau and Tualang series were used in this study. The first two soils were derived from marine alluvium while the third, Tualang series was of riverine alluvium origin. Both the Chengai and Tebengau contain more montmorillonitic clay than the riverine-derived Tualang (Furukawa 1976). The measured bulk density, organic matter and clay content for the topsoil, hardpan soil and subsoil layers of all three soil series are shown in Table 1.

*Procedure*

Undisturbed soil samples were collected in 144.13 cm3 ring with 5.1 cm height and 5.32 cm inner diameter at three different layers, namely, the puddled (0-20 cm), hardpan (21-35 cm) and subsoil ((35 cm) layers of the Chengai, Tebengau and Tualang soil series after harvesting the main season rice crop. Before sampling, the inner side of the ring was thinly coated with grease to prevent soil adhering to the ring. The samples collected were placed in a water tray for five days, allowing them to completely saturate. These were then weighed at complete saturation and allowed to air dry at room temperature. Weekly moisture loss was monitored for five weeks using a measuring balance (sensitive to 0.1 g) and deducting the weight loss. When there was no further weight loss the dry soil clods were put in the oven at 105°C for 48 hours to ensure complete drying. Some samples cracked due to moisture loss. Only those oven-dried samples which did not develop cracks were used for determining volume change assuming shrinkage only but no cracking.

The shrinkage volume change of each sample was determined by the ASTM D427 (mercury), modified method (sand) and ASTM D4943 (wax) method, respectively. This measurement was done thrice for each sample of five replicates and the mean value was used for the calculation of volumetric shrinkage and linear shrinkage.

*Volume Measurement of Dry Soil*

*Mercury Method:*

The volume of the dry clod was determined by mercury (Hg) displacement method (ASTM, 1974). In this method, a glass cup (250-mL) with a smooth rim 7.0 cm in diameter and 8.5 cm high was filled up with Hg and placed in an evaporating dish. The dry soil sample was placed on the Hg surface inside the glass cup and then carefully pressed until completely immersed in the liquid Hg using a steel plate having three slender prongs to keep it under the Hg surface. Excess Hg spilling over the wall of the glass cup was collected in the evaporating dish, then transferred into a 50-mL (±0.5-mL) graduated measuring cylinder and its volume measured. The volume of the displaced Hg was considered as the volume of dry soil sample. The volume change from wet to dry was determined by deducting the dry volume from the wet volume.

*Sand Method:*

Bulk samples of tin mine sand were collected from UPM campus, dried, cleaned and then sieved through a 212 μm sieve. The same 144.13 $cm^3$ ring with one end closed was used to deter-

TABLE 1
Bulk density, organic matter and clay content for three different layers of the Chengai, Tebengau and Tualang series soil

| Soil Layer ⇒ | Topsoil | | | Hardpan | | | Subsoil | | |
|---|---|---|---|---|---|---|---|---|---|
| Soil Series ⇓ | Bulk density | Organic matter (g/ce) | Clay (%) | Bulk density (g/cc) | Organic mater (%) | Clay (%) | Bulk density (g/cc) | Organic matter (%) | Clay (%) |
| Chengai | 01.10a | 03.74c | 64.92b | 01.15a | 02.98b | 64.36b | 01.16a | 01.79b | 62.99a |
| Tebengau | 01.09a | 04.70b | 67.16a | 01.12b | 03.42b | 65.55a | 01.12b | 02.92a | 63.68a |
| Tualang | 00.96b | 05.37a | 53.81c | 01.00c | 05.12a | 53.34c | 01.04c | 03.25a | 53.19b |
| CV(%) | 0.84 | 5.46 | 1.89 | 0.81 | 7.07 | 0.89 | 1.20 | 9.03 | 2.77 |
| SE (+) | 0.02 | 0.25 | 1.58 | 0.02 | 0.34 | 1.48 | 0.02 | 0.23 | 1.33 |

Means within columns bearing same letter(s) are not significantly different mine the dry volume with sand. First the dry sample was put inside the ring and then fine sand (≤ 212 (m) was slowly poured into the ring until the ring was completely filled up. During this process the ring was knocked gently several times to ensure proper filling of the sand. The top of the ring was then carefully levelled by a sharp and thin knife to remove excess sand. The sample and sand were then separated from the ring and the sand was poured into a 50-mL (±0.5-mL) graduated measuring cylinder. This volume of sand so measured is equal to the volume change of the sample from wet to oven dry.

*Wax Method:*

Clod volume was determined by a water displacement method (Blake, 1965 and ASTM, 1989). The dry soil sample was tied with a sewing thread and then immersed in melted wax gently to avoid entrapment of air bubbles. If the latter occurred the bubble was cut out using a sharp knife and the hole was allowed to be refilled with wax. After complete coating the soil sample was removed from the melted wax and allowed to cool. Coated clods were first weighed in the air followed by weighing in water. The difference in weight was used to calculate the total volume of clod and wax. Knowing the density of wax, the volume of wax was calculated and the clod volume was later determined by deducting the volume of wax from the total volume.

From the measured and recorded data volumetric shrinkage and linear shrinkage were calculated according to the following procedures.

*Volumetric Shrinkage (VS):*

Volumetric shrinkage (VS) of a soil can be defined as the decrease in volume, expressed as a percentage of dried soil mass, when the water content is reduced from an initial given percentage (Wi), approximately the plastic limit, to the shrinkage limit (SL) (ASTM, 1989). It is also defined by the following equation:

$$VS = (Wi - SL)R \qquad (1)$$

Where,

Wi = moisture content of the soil when it was allowed to dry (%);

SL = shrinkage limit (%); and

R = shrinkage ratio (R of a soil can be defined as the ratio of a given volume, expressed as a percentage of dry volume, to the corresponding water content above the SL, expressed as a percentage of the mass of oven-dried soil).

*Linear Shrinkage (LS):*

The linear shrinkage (*LS*) of a soil is the decrease in one dimension when the water content is reduced from a given value to the shrinkage limit (ASTM, 1990) and is defined as:

$$LS = 100\left[1 - \left(\frac{100}{VS + 100}\right)^{1/3}\right] \qquad (2)$$

Statistical differences in volumetric shrinkage (VS) and linear shrinkage (LS) between three methods were tested using Duncan's Multiple Range Test (DMRT). Means, coefficients of variation and standard errors were calculated for VS and LS for each layer of every soil series (Gomez and Gomez, 1984). Simple linear relationship between sand and mercury and between sand and wax methods was established for both VS and LS.

## RESULTS AND DISCUSSION

Means, coefficients of variation and standard errors calculated for VS and LS of wax, mercury and sand methods for each layer of Chengai, Tebengau and Tualang series are shown in Table 2. There was no significant difference between wax, mercury and sand methods for the calculated means of VS and LS for every layer in all three soil series. Notwithstanding this, the calculated values for the wax and mercury methods which were similar were slightly higher than for the sand method. This trend was observed in all the three layers of soil for the tested soil series. As wax and mercury were liquid substances and the shrinkage volume of the soil has been determined by the displacement of those liquids, a higher shrinkage volume was expected from these two methods as compared to the sand method. For sand, there is inter-particle space between particles of sand which influenced compaction during shrinkage volume measurement of the dry soil clod. Furthermore, as mercury and melted wax were liquid substances, they could easily enter the macropore spaces in the dry soil clod which then resulted in the larger volumes of mercury and wax as com-

TABLE 2
Volumentric shrinkage and linear shrinkage of three layers of the Chengai, Tebengau and Tualang series oil

| Soil Layer ⇒ | Topsoil | | Hardpan | | Subsoil | |
|---|---|---|---|---|---|---|
| Method ⇓ | Volumetric Shrinkage (%) | Linear Shrinkage (%) | Volumetric Shrinkage (%) | Linear Shrinkage (%) | Volumetric Shrinkage (%) | Linear Shrinkage (%) |
| | | | Chengai Series | | | |
| Mercury | 22.63a (±0.49) | 6.57a (±0.12) | 34.41a (±0.81) | 9.37a (±0.18) | 36.28a(±0.43) | 9.80a (±0.09) |
| Sand | 22.12a (±0.56) | 6.44a (±0.14) | 33.94a (±0.80) | 9.28a (±0.18) | 35.91a (±0.44) | 9.71a(±0.10) |
| Wax | 22.71a (±0.56) | 6.59a (±0.14) | 34.75a (±0.90) | 9.46a (±0.20) | 36.99a (±0.53) | 9.96a (±0.12) |
| CV (%) | 4.91 | 4.71 | 5.46 | 4.53 | 2.88 | 2.36 |
| | | | Tebengau Series | | | |
| Mercury | 22.86a (±0.76) | 6.63a (±0.19) | 33.51a (±0.71) | 9.18a (±0.16) | 34.05a (±0.34) | 9.29a (±0.07) |
| Sand | 22.47a (±0.79) | 6.53a (±0.20) | 32.95a (±0.66) | 9.07a (±0.16) | 33.57a (±0.35) | 9.20a (±0.08) |
| Wax | 22.87a (±0.73) | 6.63a (±0.18) | 33.60a (±0.72) | 9.20a (±0.16) | 34.00a (±0.39) | 9.30a (±0.09) |
| CV (%) | 7.47 | 6.56 | 4.67 | 3.95 | 2.35 | 3.95 |
| | | | Tualang Series | | | |
| Mercury | 18.67a (±0.66) | 5.54a (±0.18) | 21.71a (±0.68) | 6.34a (±0.17) | 24.19a (±0.36) | 6.96a (±0.09) |
| Sand | 18.16a (±0.70) | 5.42a (±0.17) | 21.54a (±0.72) | 6.33a (±0.21) | 24.11a (±0.42) | 6.59a (±0.10) |
| Wax | 18.61a (±0.63) | 5.53 (±0.17) | 21.70a (±0.62) | 6.49a (±0.16) | 24.29a (±0.30) | 6.99a (±0.08) |
| CV (%) | 8.07 | 7.02 | 6.97 | 6.35 | 3.34 | 2.91 |

Means within columns bearing same letter (s) are not significantly different for each soil series

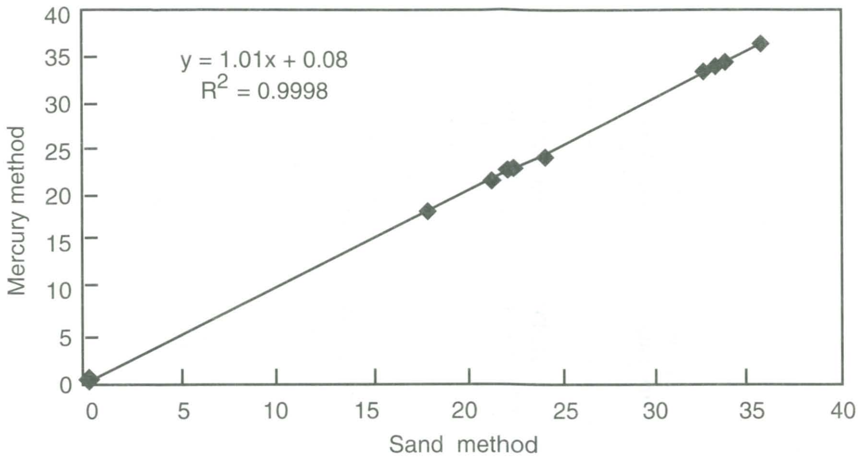


*Fig 1. Relationship between sand and mercury methods for volumetric shrinkage*

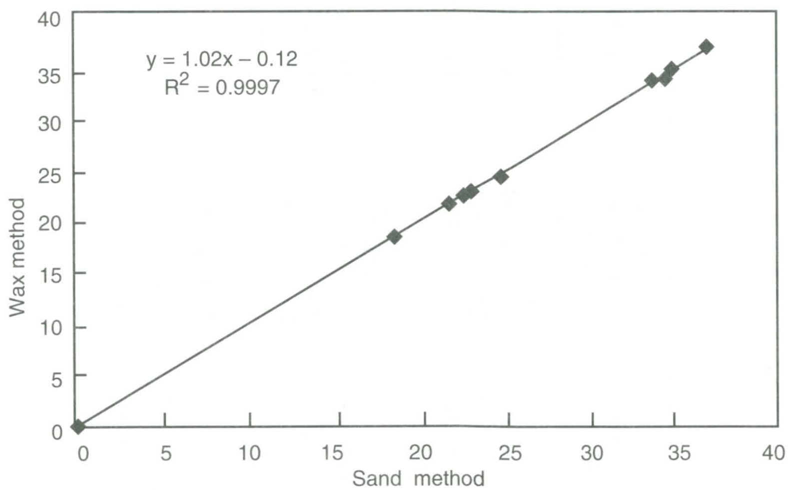


*Fig 2. Relationship between sand and wax methods for volumetric shrinkage*

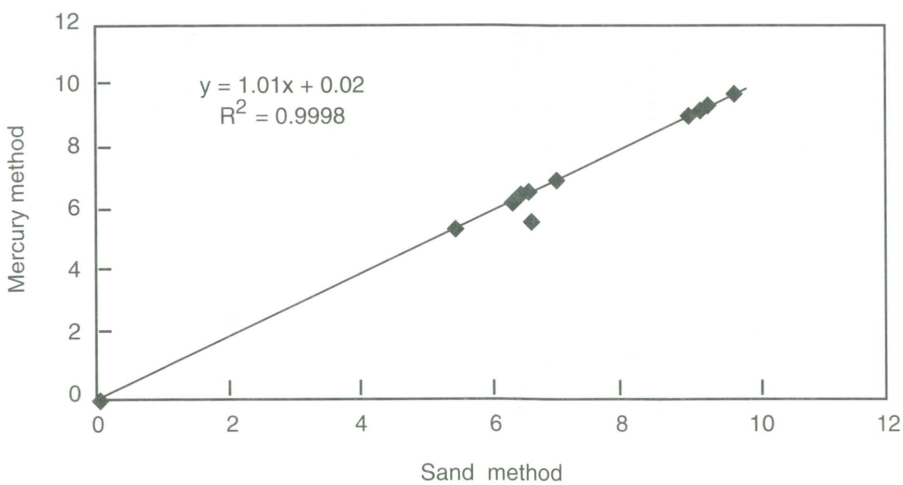


*Fig 3. Relationship between sand and mercury methods for linear shrinkage*

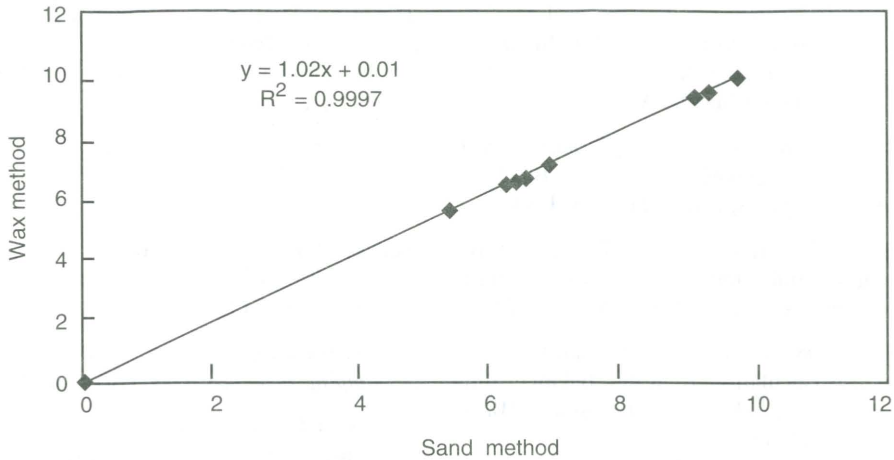


*Fig 4. Relationship between sand and wax methods for linear shrinkage*

pared to fine sand for the shrinkage volume measurements. However, the accepted experimental error as indicated by low CV (<10%) and non-significantly different VS and LS values measured by the three methods indicates the proposed method of measurement using sand instead of mercury or wax can be just as reliable.

The linear relationship between sand and mercury methods and between sand and wax methods for VS and LS are presented in *Figs. 1-4.* The computed coefficients of determination ($R^2$-value) were 0.999 for both VS and LS. These strong relationships further indicate the suitability of the sand method.

As mercury and wax are harmful substances for both health and the environment, more care and precautions are required when using them as compared to sand. Mercury is reusable but it quickly becomes contaminated and cannot be used for other purposes. The sand method is cheaper, particularly when a limited number of samples are used. In terms of time taken, the wax method is the most time consuming and the sand method the least.

In regard to the calculated values, the VS of Chengai, Tebengau and Tualang series soil were in the range 22-37%, 22-34% and 18-24% respectively and their respective LS values were 6-10%, 7-9% and 5-7% indicating similarities in Chengai and Tebengau series as compared to Tualang series. The differences could be related to clay content, which was higher in the Chengai and Tebengau series than in the Tualang series (Table1).

## CONCLUSION

The sand method as an alternative technique for measuring shrinkage of clay soils was developed because of growing concern about hazards associated with using mercury and wax in the workplace. Handling and storage of heavy metals such as mercury should be avoided when alternatives are available that reduce the hazards to researchers and prevent accidental discharge into the laboratory environment.

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