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Influence of Natural Variation on flow Behavior of Wormy Compost

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ABSTRACT: Dependence on chemical fertilizer continually is increasing. Continual increasing of using chemical fertilizer causes nature pollution (e.g. water contamination). This has led researchers to aggressively investigate renewable fertilizer resources, biomass, to produce organic crops and reduced wastage. Wormy compost is a bulk solid and biomass feed stocks. Wormy compost flow is obstacle as it often becomes confined by Clogging and bridging which occurs during storage and processing. The objective of this study was to review the primary factors affecting flow-ability and wall friction characteristics of granular solids and powders, as well as devote testing methodologies for this biomass material. It can be said that high moisture content and small particle size has an adverse effect on the flow property of wormy compost. Increasing the moisture content and decrees particle size of the wormy compost reduced its flow-ability from free flowing at moisture content of 25% (w.b.) and 1.18mm in particle size to cohesive at moisture content of 35% (w.b.) and 0.3mm in particle size. The maximum values of friction angle were occurred for Steel, Galvanized and Aluminum surface, respectively.

Key words: Adhesion,Wall friction,Cohesion, Flow properties,Genike,Shear tester,Wormy compost

INTRODUCTION

Biomass are organic materials including but not limited to agricultural wastes, food, feed and fiber crop residues, aquatic plants, forestry and wood residues, bio based segments of industrial and municipal wastes (Fasina, 2008; Rasapoor *et al.,* 2009; Senturk *et al.,* 2013; Abduli *et al.,* 2013; Song *et al.,* 2013; Amirabedin and McIlveen-Wright, 2013; Shafieiyoun *et al.,* 2012; Mahmoudkhani *et al.,* 2012; Adl *et al.,* 2012; Nada *et al.,* 2012; Gusterova *et al.,* 2012; Ghaderi *et al.,* 2012). Processing organic waste in different ways can be done in certain places if it is possible. However, new methods of recycling can effectively reduce pollution in the environment and make waste materials to useful materials (Jokari *et al.,* 2012; Rashidi *et al.,* 2012; Brisolara *et al.,* 2012; Nwabanne *et al.,* 2009; Nasrabadi *et al.,* 2008; Mavaddati *et al.,* 2010) . Therefore the low-cost production technology of wormy compost that could be run by minimal facilities is taken in many regard by public, bring many economic resources. The vermicomposting is stabilization of organic material through the joint action of earthworms and microorganisms. While microbes are responsible for biochemical degradation of organic matter, earthworms are the important drivers of the process, conditioning the substrate and altering the biological activity (Surindra Suthar, 2009). This proses led to produce powder-like fertilizer named wormy compost. Flow properties of powder-like materials are quantified by means of flow index, cohesion and angle of internal friction. Details of the determination of the flow behavior of materials can be found in Jenike (1964) and Fitzpatrick et al. (2004). The flow function is used to characterize the flow-ability of a material. It is obtained from the inverse of the flow function. The flow function is the slope of the plot of unconfined yield stress versus the major consolidating stress that is obtained when the material is sheared to failure in a shear cell (McGlinchey, 2005). Major Principal Stress in the steady state flow is called major consolidation stress (σ_1), acting on critical consolidation condition, is determined by drawing the Mohr circle (steady state Mohr circle) passing through the point (σ, τ_c).

This classification is given in Table 1. The aim of present work is to evaluate the influence of moisture content, particle size and consolidation on wormy compost flow-ability.

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Table 1. classification of powder flow-ability by index(FI)

flow-ability	Hardened	Very cohesive	Cohesive	Easy flowing	Free flowing
Flow function(FI)	<1	<2	<4	<10	>10

The ratio FI and thus the flow-ability of a specific bulk solid change with consolidation stress In addition, it is generally assumed that materials with a cohesion of >2 KPa and angle of internal friction <30 (degree) are amenable to handling using gravity alone (McNeill, *et al.,* 2004). Changes in particle properties (moisture content, particle size) and storage conditions may influence the flow-ability of powders; sometimes even small changes can have significant effects. Storage conditions include storage temperature, exposure to humidity of air, storage time, and consolidation (Fitzpatrick *et al.,* (2004b), Horabik., 2001, Teunou and Fitzpatrick, 1999).

Moisture content usually has a significant impact on powder flow-ability. Increasing moisture content leads to reduced flow-ability due to the increase in liquid bridges and capillary forces acting between the powder particles. Dependence of powders flow on particle shape and size distribution, on temperature and relative humidity, but they have been proved difficult to relate to features at particulate level. Thus, a more fundamental and physical measurement should be easily achievable using shear cells (Horabik and Grochowicz , 2002, Jenike, 1964, Kamath, et al., 1993, Schulze, 1996). Wall friction angle, φ_X, is the arc tangent of the coefficient of sliding friction between the bulk solid and hopper wall material. A suitable method for determining angle of wall friction in the literatures is Jenike's test (Schulze 1996 a, b, Bernhart and Fasina, 2009; Schulze, 2008b,). Pillai et al, 2007 investigated that it can be studied that both the Jenike (off-line tester) and the online tester showed the same trend, though there are some variations seen quantitatively. The main disadvantage of the Jenike's test is that it is difficult to conduct (Schulze 1996 a, b). The results of Jenike's test are often used to determine the minimum hopper angle and the opening size for a mass flow system (Fitzpatrick *et al.,* 2004).

Furthermore, it is possible to decide whether or not the use of a liner or polishing of the wall surface would have advantages in the flow of the bulk solid with knowing the wall friction angle (Schulze, 2008a).The wall friction angle is a complex subject because affected by many factors such as the wormy compost moisture content and material source (effecting the chemical composition) and type of structural wall surface material (Prescott *et al.,* 1999).

MATERIALS & METHODS

Samples of wormy compost selected from Karaj campus that was produced by the College of Soil Science in the wormy culture farm, west north of Tehran, Iran. The average moisture content was 15% (w.b.). Biomass samples were ground using a hammer mill (Glen Mills Inc., NJ) with three different hammer mill screen sizes (1.18, 0.6 and 0.3 mm). A sample of 100 g was placed in a stack of sieves. The sieve series selected were based on the range of particles in the sample. The set of sieves was placed on the Ro-Tap sieve shaker (Tyler Industrial Products, 507-007 Ro-Tap Sieve Shaker). The duration of sieving was about 10 min, which was previously determined through experiments to be optimal. After sieving, the mass relict on each sieve was weighed. Sieve analysis was repeated three times for wormy compost. The particle size was determined according to ANSI/ASAE standard S319.3 JUL 97. The geometric mean diameter (dgw) of the sample and geometric standard deviation of particle diameter (Sgw) were calculated according to the aforementioned standard.The moisture content of the wormy compost was determined following the procedure given in ASTM Standard D 3173-87 for coal and coke. One gram of pulverized sample passing through sieve number 50 was taken and oven-dried for 12 h at 103$^{\circ c}$. The amount of water is needed for add specimens were calculated using the following equation (Eq. (1)):

$$m_w = \frac{m_i (M_{wf} - M_{wi})}{1 - M_{wf}} \quad (1)$$

m_w is mass Water added (g), m_i is The initial mass of fresh manure (g), M_{wi} is the initial moisture content of manure (w.b%), M_{wf} is the final moisture content (w.b.%). The samples were wetted by sprinkling water on them to moisture contents of 25%, 30% and 35% (w.b.) and stored in a cooler kept at 4 $^{\circ c}$ for a minimum of 72 h. Chemical composition of samples were analyzed by a commercial animal feed testing laboratory in Abureyhan campus of Tehran University (Environ-test Laboratory) according to the AOAC standard methods. All measurements were accomplished with a Jenike shear cell. The Jenike's shear tester was developed by Rahmanzadeh et al. (2011). This device has three main components including a shallow stainless steel ring with diameter of 95 mm, a driving unit (AC electric motor, inverter and reduction unit) and a data acquisition (load cell with resolution of 0.02 N, indicator, PC interface and software). The steel ring was rested on a sample of wall material which was fixed to the base plate of the tester. For any flow function, four yield loci and four points for each yield locus were obtained. To construct a yield locus, the powder was critically consolidated under a known normal consolidating stress, σ_1, and the shear stress, (τ), required to cause the powder to fail under 75, 50, 25% of consolidating stress (normal stress σ), and applied the load head began to twist the cell lid at a speed of 2.5 mm/min, thereby causing the sample to shear also the consolidating stress were measured. A yield locus is a plot of failure shear stress versus normal stress for a given consolidating stress. This is repeated for four different consolidating stresses to obtain four yield loci. Every point of the yield locus was repeated three times The liner Mohr-Coulomb equation (Eq. 2) was fitted to yield locus to estimate the cohesion and internal friction angle. Geometric methods were used to estimate σ_1 and σ_c (Puri, 2002). The flow function for the sample was then obtained from the slope of the plot of σ_1(UYS) versus σ_c (MCS). The details of these calculations can be found in Puri (2002). The flow function therefore gives the stress needed to make an arch (formed when flow from a hopper stops) collapse as a function of the compacting stress under which it was formed (Williams, 1990). The ratio of the σ_1 / σ_c is the flow function.

$$\Gamma\ (Z)\tan + \mathbf{c} = \Delta \qquad (2)$$

Where τ is shear stress (kPa), σ is normal stress (kPa), φ is angle of internal friction (degrees) and c is cohesion strength (kPa).

The methodology and equipment described for determining flow-ability of wormy compost with shade of doing process was used for the determination of angle of wall friction and adhesion to three wall surfaces (steel, galvanize steel and aluminum) except that the bottom base ring section of the shear cell (the base ring previously contained wormy compost) was replaced with a cylindrical mold manufactured from the wall material of interest. Also To homogenize and Consolidation the wormy compost sample within the rings a solid lid was placed on the top of the mold ring and compressed by 100 N loads. After this pre-compaction, the load, mold ring and lid were carefully detached from the steel shear cell ring and excess material was scraped with a knife. During the test the wormy compost sample was moved relative to the different wall friction surfaces. To measure the wall friction normal load, was applied to the lid. The tests was started with the largest wall normal stress, σ=17 kPa, and then incrementally decreased the wall normal stresses (13, 7 and 0 kPa) once a constant wall shear stress has been attained. When the shear stress reaches a constant value, load was removed until the normal stress was reduced to the next level. When the shear stress has been again became constant, the normal load was again reduced and so on until the constant shear stress had been measured at all selected stress levels, σ.

RESULTS & DISCUSSION

The chemical composition of wormy compost tested for mechanical properties is presented in Table 2. Among chemical components, the attendance of protein and lignin may enhance the flowing property of biomass powders. The content of lignin in wormy compost improves the binding characteristics of compacted materials during the temperature increment due to stow of the material. The content of lignin is lower protein than in wormy compost. Protein plays a main role as a binding factor between particles during compaction. It is worth mentioning that the high ash content of the wormy compost implies that about one-third of the total compost will have to be removed as residue if this material were used for combustion. This residue will mostly contain minerals and therefore could be a valuable source of fertilizer.

Table 3. Shows the geometric mean diameter, bulk density and particle density of six wormy compost species. It can be observed that the larger the screen openings, the lower were the bulk and particle densities.

Table 2. Chemical composition of wormy compost

Components Biomass species	Protein DM[a]	Crude fat DM	Lignin DM	Cellulose[b] DM	Hemicellulose[s] DM	Ash DM
Present of content (%)	10.4	3.2	2.3	5	7.2	32.3

[a]DM—dry matter.[b]Cellulose percentage is calculated indirectly from acid detergent fiber (ADF) and lignin (ADF–lignin). [c]Hemi-cellulose percentage is also calculated indirectly from neutral detergent fiber (NDF) and ADF (NDF–ADF).

Table 3. Physical properties of wormy compost

Moisture content (%, w.b.)	Hammer mill screen size (mm)	Geometric mean diameter (mm)	Geometric standard deviation (mm)	Bulk density (g/cm^3)	Particle density (g/cm^3)
	0.3	0.174	0.214	0.854	1.652
	0.6	0.211	0.387	0.814	1.554
25	1.18	0.246	0.312	0.732	1.493
	0.3	0.232	0.362	0.77	1.587
	0.6	0.253	0.436	0.736	1.545
	1.18	0.274	0.364	0.689	1.466
	0.3	0.237	0.394	0.743	1.543
30	0.6	0.282	0.466	0.685	1.531
	1.18	0.288	0.412	0.658	
35					1.443

Bulk and particle densities of dry and finest were higher than that of other sample. Wormy compost in 25% moister content from a hammer mill screen size of 0.3mm had the highest bulk density of 0.854 g/cm^3.

Table 3 shows that the bulk density of wormy compost decreased from 0.854 to 0.658 g/cm^3 within the moisture content range of 25–35% (w.b.) and increase particle size 0.3mm to 1.18mm. This means that the rate at which wormy compost particle volume increased was faster than the rate at which the mass of the particles increased as a result of moisture addition. Therefore, the amount of volume that will be required to store a unit mass of wormy compost will increase as moisture increases. The reduced bulk density of wormy compost with moisture content increase is similar to the reported bulk density-moisture content relationship for biomass (poultry litter- Fasina, 2008) and granular biological materials (cashew nut – Balasubramanian, 2001; alfalfa cubes and pellets; green gram – Nimkar and Chattopadhyay, 2001). The measured bulk density of wormy compost (>0.658 g/cm^3) was also considerably higher than the values that have been reported for other bioenergy feedstock such as switch grass and peanut hulls (typically <0.2 g/cm^3). This is because of the relatively high amount of ash (32% – Table. 3) present in wormy compost.

The particle density of wormy compost decreased from 1.652 to 1.443 g/cm^3 as its moisture content increased from 25% to 35% (Table. 4). This shows that the volume of the particles of the wormy compost increased at a higher rate than the increase in mass as moisture content increased. A similar trend was observed in various biological materials by Deshpande et al. (1993), Joshi et al. (1993), Fasina (2008) and Nimkar and Chattopadhyay (2001).

The ultimate yield stress, σ_1 (UYL) versus the major consolidating stress, σ_c (MCS) at various moisture contents. The flow function decreased with moisture content. This indicates that the stress needed to make an arch (formed when flow from a hopper stops) collapse (Teunou, and Fitzpartick, 2000) increased with moisture content. Using the classification of Jenike (1964), the flow function values indicate that the flow-ability of wormy compost reduces as moisture content increased (Fig.1). Teunou and Fitzpatrick (1999) MSC(Kpa)also found similar results when they compared the flow functions of flour (at 12.0% moisture content), tea (at 6.5% moisture content), and whey (at 4.0% moisture content) (Teunou and Fitzpatrick,1999).They concluded from their study that the flour with the highest moisture content had the most difficult flow.

As expected, the cohesion for wormy compost was significantly ($P < 0.01$ and $P \geq 0.05$) affected by moisture content, particle size and applied pressure. The angle of internal friction for wormy compost was also significantly ($P \geq 0.05$) affected by moisture content, particle size and applied pressure. The cohesive strength data are generally lower than the values obtained for high-rising wheat flour (1.5–3.5 KPa), for fine tea powder (1.0–2.3 KPa) (Teunou and Fitzpartick, 2000) poultry litter (0.41–3.26 KPa), and for chickpea flour and components (3.22–7.11 KPa) (Emami and Tabil, 2007) but comparable to the values obtained for spray dried whey permeate powder (0.5–1.0 KPa) and for sugar and wheat flour (0.6–1.3 KPa) (Kamath, *et al.,* 1993). The measured angle of internal friction and cohesive strength in most cases were greater than the critical values of <30 and 2 KPa required for gravity

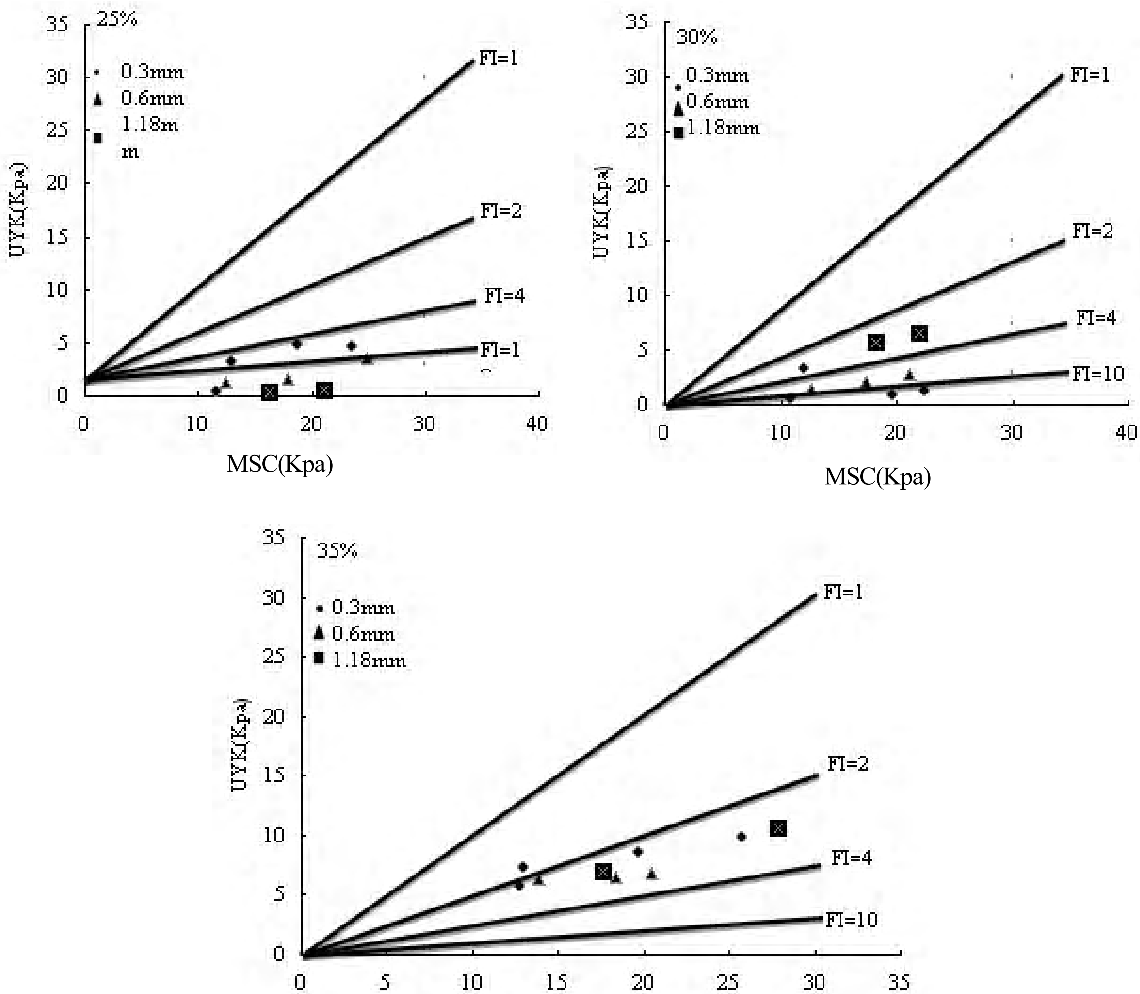

Fig. 1. Unconfined yield stress, ó$_1$ versus major consolidating stress, ó$_c$ for wormy compost in three different surface type

discharge of bulk materials from storage bins and silos (Puri, 2002). Therefore, gravity discharge alone may not be used to unload wormy compost from storage bins and silos.

The Jenike kinematic wall friction tests on wormy compost were conducted at 81 different combinations of sample of the wall material (3 type), mesh size (3 level) and frictional surface types (3 types) with 3 replication. The ultimate yield stress, σ_1 (UYL) versus the major consolidating stress, σ_c (MCS) at various surface type. The flow function on surfaces decreased with moisture content. Using the classification of Jenike (1964) given in Table. 1, the flow function values on surfaces indicate that the flow-ability of wormy compost reduces as moisture content increased (Fig.2).

As shown in these Figures, with increasing moisture the flow function increased significantly ($P< 0.01$) as well as with replacing surface type to steel, galvanized steel and aluminum respectively the FI increased significantly ($P < 0.01$) and with increasing particle size from 0.3mm to 1.18mm the FI increased ($P < 0.05$) significantly (Table 4).

Fig. 2 shows that the flow function on surfaces was increased with replacement of surface from steel to galvanize steel and aluminum respectively. Based on the slope of the linear fit to the flow index plots (Fig. 2), wormy compost will be adhesive to a steel surface. Previous research for Preparation Pellets by Urban Waste compost showed the similar trend for affection of particle size and surface types for example iron and aluminum on flow property also their interaction had significant effect on coefficient of friction (Mavaddati *et al.*, 2010). The values of wall angle of friction are higher than those obtained for sawdust and coal (Zulfiqar *et al.*, 2006), for three food powders (flour, tea and whey permeate powders – Iqbal and Fitzpatrick, 2006), for woodchips (Zulfiqar *et al.*, 2006) and poultry litter (Bernhart and Fasina, 2009).

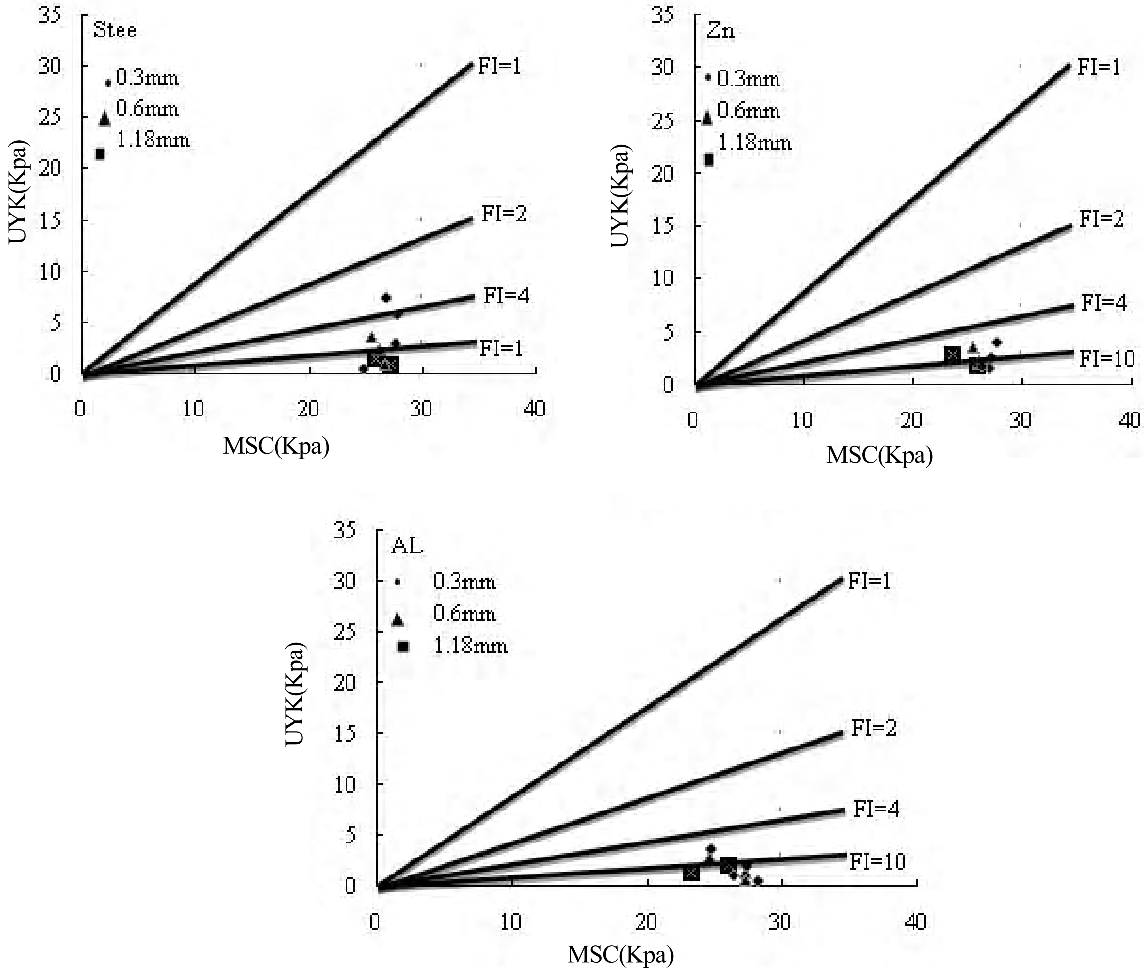

Fig. 2. Unconfined yield stress versus major consolidating stress for wormy compost in three different surface type

Table 4. Adhesive strength and angle of wall friction of wormy compost on three surfaces

Moisture content (%, w.b.)	Surfaces type: Steel			Surfaces type: galvanized steel				Surfaces type: aluminum			
	Particle size(mm)										
	0.3	0.6	1.18	0.6	0.3	0.6	1.18	0.6	0.3	0.6	1.18
	Adhesive strength (KPa)										
25	0.97	0.09	0.40		0.91	0.73	0.38		0.61	0.40	0.18
30	1.05	0.93	0.70		0.93	0.82	0.77		0.64	0.43	0.26
35	1.18	0.95	0.77		1.03	0.89	0.83		0.88	0.63	0.39
	Angle of wall friction (º)										
25	41.46	42.30	43.63		36.02	39.45	43.74		40.99	41.74	42.30
30	39.64	40.78	42.01		38.40	39.90	42.70		39.39	40.46	41.61
35	37.20	37.62	39.06		37.18	39.01	40.99		39.03	40.36	41.42

CONCLUSION

The results presented in this study indicate the importance of moisture on the storage, handling and flow properties of wormy compost. Results obtained indicate that an increase in moisture content and decrease in particle size reduced the self flow-ability and flow-ability on surfaces of wormy compost. Higher angles of internal friction are due mainly to interlocking among particles during direct shear and depend very much on the normal stress. However, friction values are intrinsic and have the potential to be effectively used for bulk characterization. Further work would be needed to document if variations in composition will affect the conclusions reached in this study. The test results show that the maximum values of angle of wall fraction was occurred for steel surface, Galvanized surface and Aluminum, respectively. Moisture content had a significant decreasing effect on the angle of wall friction measured by jenike's methodology. Particle size had a significant decreasing effect on the angle of wall friction measured by jenike's methodology.

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