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Research Article

AN EXPERIMENTAL STUDY OF ANGLE OF REPOSE OF AGGREGATES AND ITS CORRELATION WITH THE SHAPE PARAMETERS

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ABSTRACT

In the present work aggregates from a single source is used. The angularity levels of the aggregates are changed by crushing or polishing. The angle of repose values of crushed, natural and polished aggregates for different sizes are estimated. Subsequently an improvement in the method of measurement of angle of repose is suggested. Shape parameters of aggregates (*Shape factor* and *Sphericity*) are computed using Image processing the method given by Mora and Kwan (2000). Finally dependency of angle of repose of aggregate heap on shape of aggregate has been found out.

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INTRODUCTION

One of the important properties of non-cohesive granular material is angle of repose. Angle of repose the maximum slope angle at which the material at rest. Some early researchers referred angle of repose as angle of internal friction but Stewart (1968) experimentally shown that the two angles are different. The angle of repose is of two types static and dynamic. According to Chukwu and Akande (2007)

- **Static angle of repose:** This is the angle of friction taken up by a granular material about to slide upon it.
- **Dynamic angle of repose:** This is related to a situation where a bulk of the materials is in motion such as movement of solid discharging from a bin and hopper.

Burkalow (1945) performed a lot of experiments to find out the dependency of angle of repose on physical and geometrical properties of fragments (particles of granular media). He concluded that the angle of repose varies:

- Inversely with size of fragments in perfectly sorted materials, but directly in those imperfectly sorted.
- Inversely with density of fragments.
- Directly with their angularity, roughness, and degree of compaction.
- Inversely with height of fall of material on free cones.

- Directly with increase of moisture up to the saturation point but inversely beyond that.

The theoretical studies primarily involved simulation through Discrete Element Method (DEM). Lee and Herrmann (1993) showed that a linear relationship exists between angle of repose and static coefficient of friction.

Zhou *et al.* (2001) presented a numerical study on mono-sized spheres. They showed that angle of repose is dependent on coefficient of sliding, rolling friction and size of particle. They concluded that coefficient of sliding and rolling frictions are prime factors for stabilizing piles. They observed that the angle of repose increases with increase of coefficients of sliding and rolling frictions, and the angle of repose decreases with the increase in size (this effect is due to effect of size in on rolling coefficient of friction).

Salah *et al.* (2005) performed simulations on two-dimensional non-elongated and elongated polygon particles. They showed that particle shape and coefficient of friction are crucial factors that affect angle of repose. They found that angle of repose (i) increases with increase in coefficient of friction and (ii) decreases with increase in number of corners of polygon particles.

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Mora and Kwan (2000) proposed a method of finding the dimensions Length, Width and Thickness of a particle using Digital Image Processing. From digital image two dimensions length and width are computed. He proposed a method of calculating thickness with an assumption that aggregate particle from same source have more or less same shape characteristics. $mean\ thickness = \lambda \times breadth$

Where λ is a parameter dependent on the flakiness of the aggregate

He showed method to calculate λ and then Sphericity and shape factor is calculated as

$$shape\ factor = \lambda \sqrt{\frac{breadth}{length}}$$

$$sphericity = \sqrt[3]{\lambda \times \left(\frac{breadth}{length}\right)^2}$$

Thus, simulation studies show the angle of repose of aggregates is influenced by coefficients of sliding and rolling friction of the particles. It can be hypothesized that sliding friction is possibly due to small-amplitude variations, like, texture of the aggregate surface, and rolling friction is possibly due to large-amplitude variations, like angularity.

Fowler and Chodziesner (1958) carried out experiments on dry wheat, rice and different types of sand to determine the variable affecting angle of friction. They found the angle of friction (θ) depends on shape factor (f_s), specific gravity (S_1), diameter of particle (D) and roughness (ϵ) of the surface.

$$\mu = \tan\theta = \frac{0.2110}{f_s^2} + 0.3436\left(\frac{\epsilon}{D}\right)^{0.5} - 0.0171S_1 + 0.1834$$

The equation predicts sliding angle of dry material within the ranges $f_s = 067$ to 160 , $S_1 = 1.103$ to 11340 , $D = 0.0272$ cm to 04026 cm and $\epsilon = 0.0272$ cm to 0.3134 cm.

Experimental Study

Material used

Aggregate from Single source Jhansi is taken and divided in three categories.

1. Crushed - freshly crushed in laboratory
2. Normal - as taken from market
3. Polished - polished in Los-Angeles apparatus

Crushed aggregates has been prepared by crushing the aggregates in the laboratory and polished aggregates are prepared by polishing the aggregates in in Los-Angeles apparatus. Freshly crushed aggregates and polished aggregates are shown in Figure 1



A Crushed aggregates



B Polished aggregates

Figure 1 Figure showing Crushed and polished aggregates

Four sizes of all the three categories of aggregates are taken and the notation used for the sizes and types are shown in Table 1.

Table 1 Notations used for referring aggregates

size (mm)	Type of aggregates		
	Crushed	Normal	Polished
19.0-13.2	C _{13.2r}	N _{13.2r}	P _{13.2r}
13.2-9.5	C _{9.5r}	N _{9.5r}	P _{9.5r}
9.5-4.75	C _{4.75r}	N _{4.75r}	P _{4.75r}
4.75-2.36	C _{2.36r}	N _{2.36r}	P _{2.36r}

Proposed method for measurement of angle of repose

In this study a new method of angle of repose measurement is proposed in which a circular raised pedestal of different diameters are used to make the heap of aggregates. The height of the heap is measured and angle of repose is calculated as.

$$AOR = \tan^{-1}\left(\frac{2 \times h}{d}\right)$$

Where 'h' is the height and 'd' is the diameter of heap. The raised pedestal method is introduced to avoid the errors of perfect circular base induced in making the heap of ground. Figure 2 is showing the heap of aggregates on a raised pedestal. Using this method angle of repose of all the three categories of aggregates for the four sizes mentioned are measured and listed in the Table 2.



Figure 2 Figure showing the heap of aggregates on raised pedestal

Table 2 Angle of repose of aggregates determined by proposed method

size	Aggregate type		
	Crushed	Normal	Polished
19.0-13.2	47.14	44.21	43.76
13.2-9.5	45.03	43.46	42.35
9.5-4.75	44.05	41.71	40.74
4.75-2.36	41.62	40.94	40.73

Computation of shape parameters

Two shape parameters Shape factor and Sphericity for 12 set of aggregate ($C_{13.2r}$, $C_{9.5r}$, $C_{4.75r}$, $C_{2.36r}$, $N_{13.2r}$, $N_{9.5r}$, $N_{4.75r}$, $N_{2.36r}$, $P_{13.2r}$, $P_{9.5r}$, $P_{4.75r}$ and $P_{2.36r}$) are computed using Digital Image Processing (DIP).

50 aggregate sample randomly taken from each set. The image of each set of aggregates is taken from laboratory camera and is processed in Imagej software to remove noise. Method proposed by Mora and Kwan in... is used to find out Shape factor and Sphericity. Code in Matlab is written to find the length, width and thickness of each aggregate. Length and width is determined by bounding aggregates with the minimum area rectangle as shown in Figure 3 and the thickness is computed taking the assumption that the aggregate form same source have more or less same shape characteristics.

$$\text{mean thickness} = \lambda \times \text{breadth}$$

Where λ is a parameter dependent on the flakiness of the aggregate

The image of 50 samples of $C_{13.2r}$ and $P_{13.2r}$ are shown in Figure 4 and Figure 5 receptively.

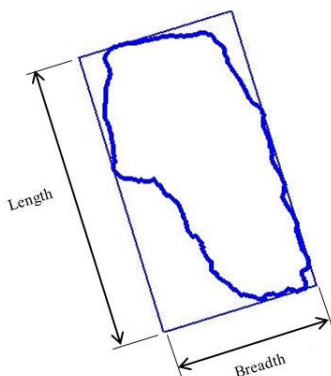
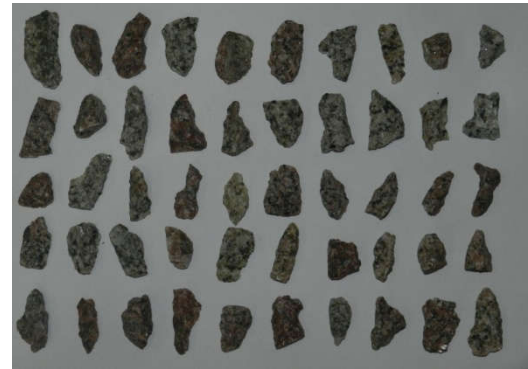


Figure 3 Computation of length and breadth



a $C_{13.2r}$ aggregate

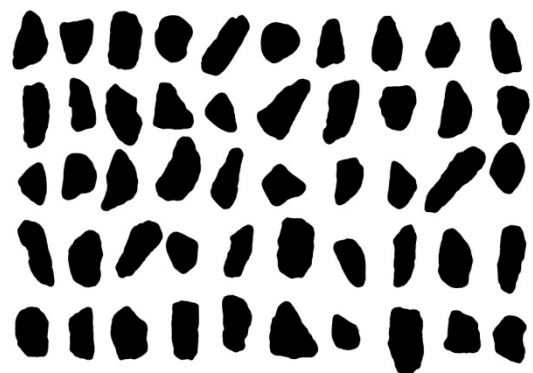


b Processed image of $C_{13.2r}$ aggregate

Figure 4 Figure showing $C_{13.2r}$ aggregate and its processed image



A $P_{13.2r}$ aggregate



b Processed image of $P_{13.2}$ aggregate

Figure 5 Figure showing $P_{13.2r}$ aggregate and its processed image

Adding the volume of all the particles and multiplying by density ρ , the total mass M is given as

$$M = \rho \times \lambda \times \sum_{i=1}^n (\text{breadth} \times \text{area})$$

The parameter λ is computed as

$$\text{volume} = \text{mean thickness} \times \text{area} = \lambda \times \text{breadth} \times \text{area}$$

Adding the volume of all the particles and multiplying by density ρ , the total mass M is given as

$$M = \rho \times \lambda \times \sum_{i=1}^n (\text{breadth} \times \text{area})$$

Where n is the total number of particles in this case n is 50. From the above equation λ is computed as.

$$\lambda = \frac{M}{\rho \times \sum_{i=1}^n (\text{breadth} \times \text{area})}$$

Now shape factor and sphericity of each aggregate is calculated as.

$$\text{shape factor} = \lambda \sqrt{\frac{\text{breadth}}{\text{length}}}$$

$$\text{sphericity} = \sqrt[3]{\lambda \times \left(\frac{\text{breadth}}{\text{length}}\right)^2}$$

The average of 50 Shape factor and Sphericity values give the Shape factor and Sphericity for the 12 set of aggregates and the values are shown in Table 3.

Table 3 Shape factor and sphericity values computed from Matlab

aggregate type	λ	Shape factor	sphericity
C _{13.2r}	0.270	0.203	0.443
C _{9.5r}	0.313	0.248	0.500
C _{4.75r}	0.372	0.304	0.552
C _{2.36r}	0.330	0.285	0.569
N _{13.2r}	0.353	0.275	0.509
N _{9.5r}	0.324	0.267	0.533
N _{4.75r}	0.394	0.321	0.559
N _{2.36r}	0.379	0.326	0.594
P _{13.2r}	0.373	0.288	0.512
P _{9.5r}	0.380	0.295	0.519
P _{4.75r}	0.407	0.328	0.559
P _{2.36r}	0.385	0.336	0.608

RESULTS

The angle of repose of all the three categories for four sizes has been found and correlated with the shape parameters *sphericity* and *shape factor*. The results are shown in Table and Figure and Figure.

Table 4 Angle of repose for different types with its shape parameters

Type	AOR	Shape Factor	Sphericity
P 2.36	40.73	0.3358	0.6077
P 4.75	40.74	0.3283	0.5590
N 2.36	40.94	0.3264	0.5944
C 2.36	41.62	0.2848	0.5685
N 4.75	41.71	0.3207	0.5591
P 9.5	42.35	0.2955	0.5193
N 9.5	43.46	0.2671	0.5333
P 13.2	43.76	0.2878	0.5121
C 4.75	44.05	0.3040	0.5520
N 13.2	44.21	0.2745	0.5089
C 9.5	45.03	0.2483	0.5001
C 13.2	47.14	0.2030	0.4430

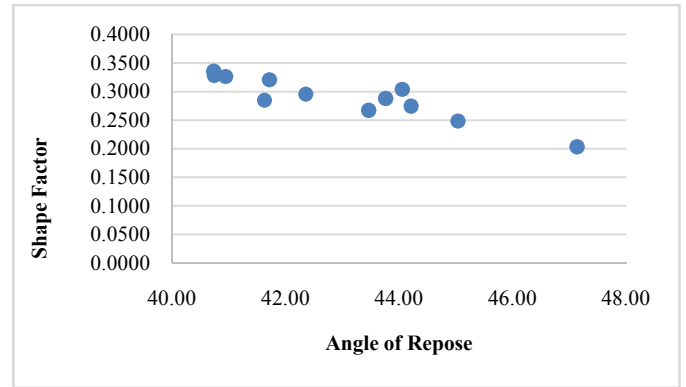


Figure 6 Chart showing correlation between angle of Repose and shape factor

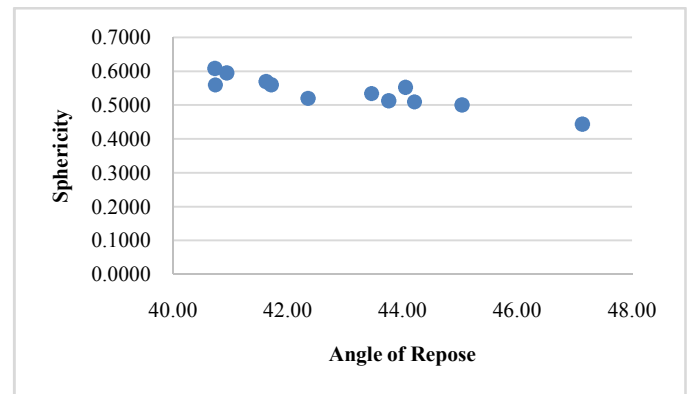


Figure 7 Chart showing correlation between Angle of Repose and Sphericity

DISCUSSION

The method proposed by Mora and Kwan found quite suitable for finding the shape properties of aggregates. The results of Shape parameters shows that as the angularity of the aggregates increases the interlocking between the aggregates get enhanced, as a result the stable piles make steeper angle with the horizontal and angle of repose is increased. Also as the size of aggregate decreases the shape is tending towards the sphere and hence angle of repose decreases.

CONCLUSION

Angle of repose of a pile is found to strongly dependent of the shape of aggregates. As the Shape became more angular the angle of repose of the pile increases and as the shape tends to spherical by polishing the angle of repose decreases. The following conclusions have been made from the present study.

- Proposed method for the measurement of angle of repose is found to be more realistic and accurate
- *Shape factor* is observed to decrease with the increase of angle of repose.
- *Sphericity* is also observed to decrease with the increase of angle of repose.

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