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# Effect of Surface Roughness on Wall Friction Angle for Various Liners

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***Abstract: The design of the bulk handling equipment should be done very effectively. Although the design of this equipment might look simple, it can easily become costly in maintenance if it is not designed properly. A designer should consider parameters like surface roughness and wall friction angle, etc for a better effective design. Considering these parameters in design will not only improve the performance of equipment, but it will also reduce wear and tear of bulk solid handling equipment. The objective of this study is to establish a regression curve between the surface roughness and wall friction angle and to showcase the effect of surface roughness on the wall friction angle.***
***Keywords: Bulk solid, surface roughness, wall friction angle, line of regression, surface roughness tester***

## I. INTRODUCTION

### *A. Surface Roughness*

Surface quality is a crucial measure of the quality of machining, while surface roughness is one of the most vital and basic variables. It has an impact on the performance and service life of machinery and instruments. Machine parts that have inspected below magnification can have some irregularities on the surface. The higher the smoothness of the surface, the better is the fatigue strength and corrosion resistance. Surface roughness is the random deviation from the nominal surface. Surface roughness promotes adhesion in the case of bulk materials.

Roughness is defined as close-spaced uneven deviations at the microscale level, it expressed with reference to width, height, and distance along the surface of the components. In simpler words surface of the component is a union of valleys and peaks that we measure this as surface roughness. To measure surface roughness, there are many parameters like $R_a$, $R_q$, Rz, and $R_{sq}$ (2D parameters). There are 3D parameters as well, but they are not extensively used. $R_a$ is the most commonly used parameter. $R_q$, Rz, and $R_{sq}$ are used only in a few industries or within a few countries. The subscript denotes the formula that's been used. Each formula listed within table 1 below assumes that the roughness profile is filtered from the raw profile data and also the mean line has been estimated. The roughness profile consists of n ordered equally spaced points on the sampling length and $Y_i$ is that vertical distance from the mean line to an $i^{th}$ point. Height is considered to be positive in the upward direction.

The surface roughness parameters are discussed in detail below.

1) *Average roughness ($R_a$):* This is the average of the values of profile height deviations from the mean line recorded inside the evaluation length.

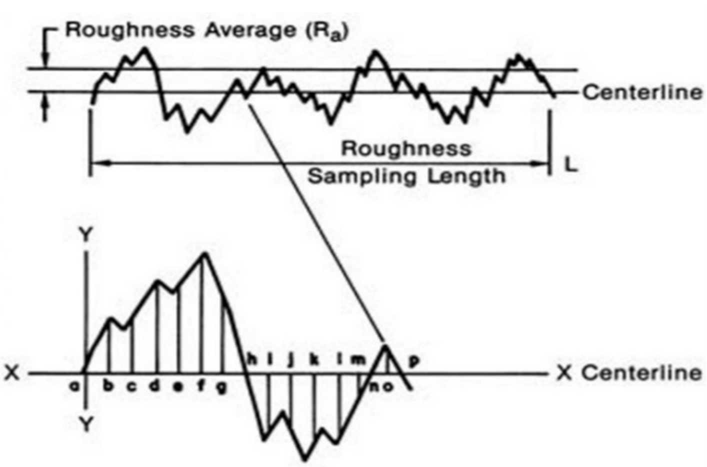


Fig. 1: Average roughness

2) *Root Mean Square Roughness (R.M.S)*: R.M.S is the square average of the profile height deviation from the mean line recorded within the evaluation length.

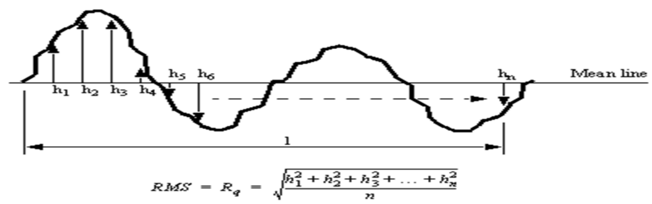


Fig. 2: RMS roughness

3) *Maximum height of the profile ($R_z$):* Sum of peak height ($P_i$) and valley depth of a profile within each sampling length

Note: Evaluation length is further divided into smaller portions called sampling lengths.

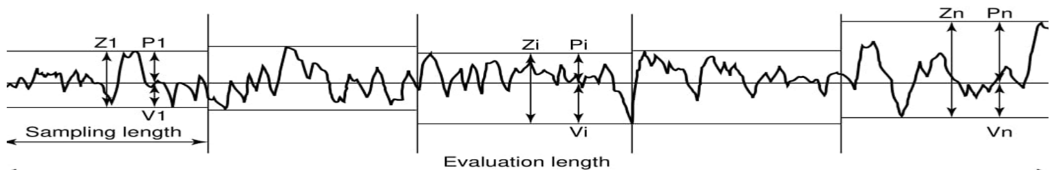


Fig. 3: Maximum height of the profile ($R_z$).

The $R_a$ values for each liner are found using a contact type of surface roughness (stylus-based) tester. There are certain standards for finding surface roughness.

| Surface roughness parameter | Formula |
|---|---|
| Average roughness ($R_a$) | $Ra = \frac{1}{n}\sum_{i=1}^{n}\lvert y_i \rvert$ |
| Root mean square roughness ($R_q$) | $R_q = \left[\left(\frac{1}{L}\right) Z(x)^2\, dx\right]^{1/2}$ |
| Maximum height of the profile ($R_z$) | $R_z = \frac{z_1 + z_2 + z_3 + z_4 + z_5}{5}$ |

Table 1: Formulae for surface roughness parameter (2 Dimensional).

## B. *Wall Friction Angle*

The wall friction angle is the friction angle between bulk solid and liner. Wall friction angle is required for designing silo, chute, determining the steepness of a hopper, etc. Wall friction angle is measured by the slope of the wall yield locus line passing through the origin. To assess wall friction, the wall friction angle ($\varphi_x$) or the coefficient of wall friction($\mu$) are used. The greater the wall friction the larger is wall friction.

Wall friction is always dependent on wall shear stress($\tau_w$) to wall-normal stress ($\sigma_w$) and sometimes constant. The coefficient of wall friction($\mu$) is defined as the ratio of wall shear stress($\tau_w$) to wall-normal stress ($\sigma_w$) for a point on the wall yield locus:

$$\mu = \frac{\tau_w}{\sigma_w}$$

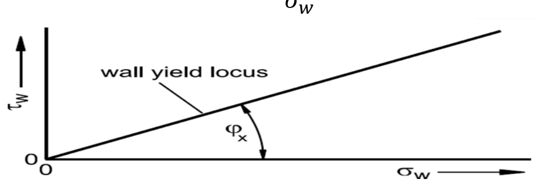


Fig. 4: wall yield locus (a constant wall friction angle)

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The wall friction angle($\varphi_x$) is the slope of the line passing from the origin of the normal stress($\sigma_w$), shear stress($\tau_w$) diagram to some extent on the wall yield locus:

$$\varphi_x = \tan^{-1}\left(\frac{\tau_w}{\sigma_w}\right)$$

Wall friction angle can be measured using jenike shear tester, ring shear tester.

## II. MATERIAL USED

### A. Liners Used

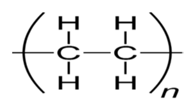
| Liner | Chemical composition |
|---|---|
| SS409M | C-10.5-11.75%, Fe- 0.08%, Ni- 0.5% |
| Mild steel | C-0.16 to 0.18 % (max 0.25%),<br>Mg-0.70 to 0.90 %, Si- max 0.40% |
| Hardox 400 | C-0.14 to 0.32%, Mn-1.60 %, Mo-0.25-0.60 %,<br>Cr-0.30 to 1.40%, Si-0.70, Ni-0.25 to 1.50 |
| SS301 | C-0.150%, Mg-2.0 %, P-0.045%, S-0.03%,<br>Si-1.0%, Cr- 16.0-18.0%, Ni- 6.0-8.0%, N-0.1 % |
| Ultra-high molecular weight polyethylene (UHMWPE) |  |
| ARCOM | C-0.010, Mn-0.06, P-0.005, S-0.003,<br>N-0.005, Cu-0.03, Co-0.005, Sn-0.005 |
| Manganese steel | C≤0.12%, Si 0.4%, Mn 0.35-0.65%, P≤0.035%, S≤0.035%, Cr 0.70-1.10%,Cu 0.45 %, Sb 0.10%, Ti 0.07%,Fe balance |

Table 2: Different liners used and their chemical composition.

### B. Bulk Material Used

| | | |
|---|---|---|
| 1. | Material (bulk solid) | Iron ore |
| 2. | The particle size of the bulk solid | 3mm(average) |
| 3. | The particle density of the bulk solid | 2.5Kg/m³ |
| 4. | Moisture content in the bulk solid | 3%<br>(saturation moisture percentage 12%) |

Table 3: Summary of bulk material

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## III. TEST PROCEDURE

### A. Surface Roughness

Surface roughness is often tested using the contact type and non-contact type methods. The contact method involves dragging a measurement tip across the surface, noncontact methods are based on imaging and microscopy principle. The contact method is the most commonly used method to measure surface roughness. In contact measurement, a stylus tip comes in contact with the surface to be examined and a piezoelectric or inductive transducer converts vertical movement into an electrical signal. The contact type roughness measurements can be affected by many factors like the measurement instrument, sample, operator, environment, etc. A diamond stylus moves over the surface of the liner for a specified distance. The radius of stylus ranges from 20 nanometres to 50 micrometres and the tip of a stylus is as small as 20 nanometres. ISO 1997 standards are followed. The surface should be free from scratches, paint. If the surface is not clean then there could be a deviation from the actual surface roughness.


Fig. 5: Mitutoyo surface roughness tester

### B. Wall Friction Test

Wall friction test is performed on a jenike shear tester. The setup of the jenike shear tester is shown in Fig. 6. Normal force and shear forces are applied using hanger and bracket respectively. The stem drives forward at a steady rate of 1 to 3 mm/min(approx.). The stem is attached to the drive system using force transducer which measures shear force. The shear displacement is restricted to twice the wall thickness of the shear ring. The consolidation of bulk solid will create shear stresses along normal stress generated by the normal force.

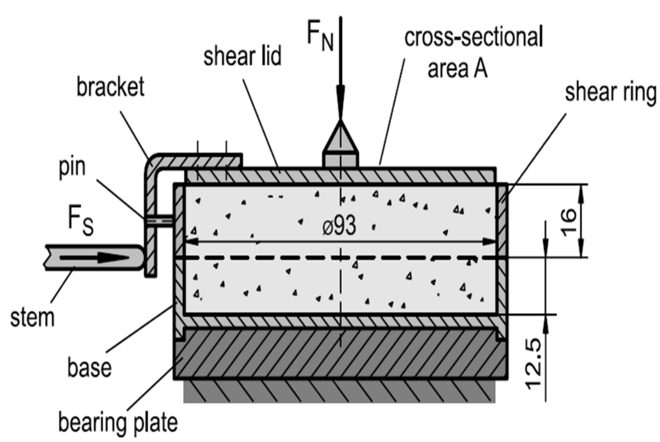


Fig. 6: Principle of a Shear cell (dimensions in mm)

The maximum shear stress is to be recognized; the stem is driven backward to reduce shear stress to zero. After measuring the first point of yield locus, more points should be to measured by repeating the same process as stated above. A fresh bulk solid sample should be used for every test.

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## IV. RESULTS AND DISCUSSIONS

### *A. Surface Roughness*

| Liner | Surface roughness ($R_a$ in micrometers) |
|---|---|
| UHMWPE 1 | 1.65 |
| Mild steel | 1.80 |
| ARCOM | 2.1 |
| Mg steel | 2.25 |
| SS409M | 2.465 |
| UHMWPE 2 | 2.56 |
| SS301 | 4.78 |

Table 4: Surface roughness of various liners

### *B. Wall Friction Test*

| Liner | Yield locus line equation (y=mx+c form) | Wall friction angle $\Theta=\tan^{-1}(m)$ |
|---|---|---|
| UHMWPE 1 | y=0.5257x | 26.3814 |
| Mild steel | y=0.4754x | 25.407 |
| ARCOM | y=0.4525x | 24.322 |
| Mg steel | y=0.4643x | 24.89 |
| SS409M | y=0.4981x | 26.44 |
| UHMWPE 2 | y=0.5257x | 27.699 |
| SS301 | y=0.5622x | 27.699 |

Table 5: Summary of wall yield locus of various liners and their wall friction angles.

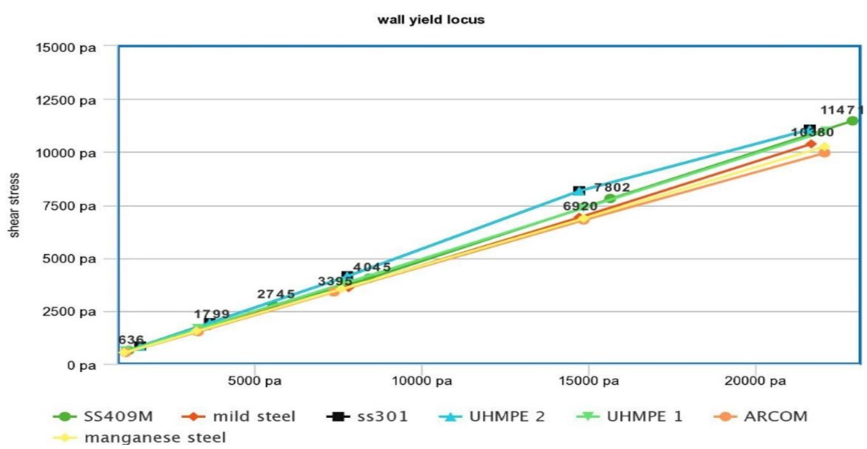


Fig. 7: Graph showing wall yield locus of various liners

## V. CORRELATION BETWEEN SURFACE ROUGHNESS AND WALL FRICTION TEST:

| Liner | Surface roughness ($R_a$ in μm) | Wall friction angle (Θ in degree) |
|---|---|---|
| UHMWPE 1 | 1.65 | 26.3814 |
| Mild steel | 1.80 | 25.407 |
| ARCOM | 2.1 | 24.322 |
| Mg steel | 2.25 | 24.89 |
| SS409M | 2.465 | 26.44 |
| UHMWPE 2 | 2.56 | 27.699 |
| SS301 | 4.78 | 27.699 |

Table 6: Surface roughness and wall friction angles of various liners

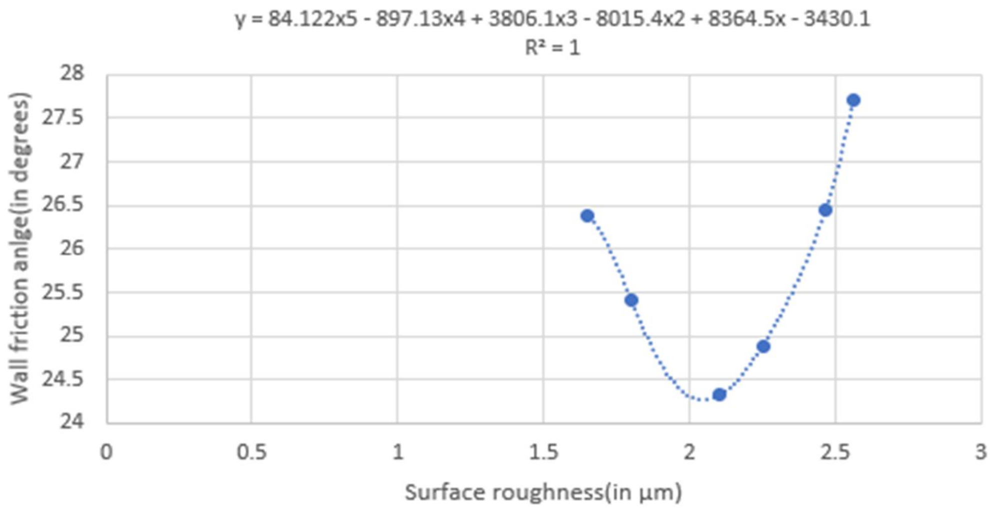


Fig. 8:Correlation between surface roughness and wall friction angle

## VI. CONCLUSIONS

Through this experimentation and study, we can conclude:

*A.* The higher value of friction is attributed to the higher value of $R_a$.

*B.* It has been proved that a definite relationship is given by equation

*C.* $y = 84.122x^5 - 897.13x^4 + 3806.1x^3 - 8015.4x^2 + 8364.5x - 3430.1$ exist between surface roughness and wall friction angle for the liners tested.

*D.* It has been also noticed that the results of wall friction are independent of the operator.

*E.* The surface roughness increases with an increase in the wall friction angle.

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