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Frictional properties of pellets and silo wall materials for the investigation of silo honking

J. Chavez-Sagarnaga[1], J. M. Buick[1,2], J. Y. Ooi[1], Pankaj[1], D. M. Campbell[3] and C. A. Greated[3]

[1] Institute for infrastructure & Environment, School of Engineering and Electronics, The University of Edinburgh, Edinburgh EH9 3JN, U.K.

[2] Department of Physics and Electronics, School of Biological, Biomedical and Molecular Science, The University of New England, Armidale, NSW 2351, Australia

[3] School of Physics, The University of Edinburgh, Edinburgh EH9 3JZ, U.K.

ABSTRACT

Silo honking is a phenomenon in which a loud acoustic emission, not dissimilar to a truck horn, occurs during silo discharge. This phenomenon has been widely reported as occurring in a wide variety of metal silos and with different fills. In this paper we present the result of experiments carried out to explore the particle-particle and particle-wall interactions for the investigation of silo honking. Two types of particles are considered: PET pellets that are known to honk and polypropylene pellets that are not. The measurements were performed using the Jenike shear tester. The shearing response showed that pellets that are known to honk exhibit slip-stick behaviour while particles that have not been observed to honk do not.

1 INTRODUCTION

Thin metal silo structures are used all around the world to store granular bulk solids such as agricultural grains, plastic pellets and mineral ores. It has been suggested that a range of different dynamic phenomena produce vibrations in a silo structure during discharge [1-3]. However, there is no consensus on theories to describe these. A number of these structures are known to emit very intermittent loud sounds similar to a truck horn, known as silo honking [2,4-6]. Although more commonly detected while silos are discharging, honking is also occasionally known to happen after a discharge period. Some of the features of silo honking are: sound pressure levels in excess of 100-110dB, high wall accelerations amplitudes [4-6], and high frequencies. Metal silos designed for mass flow containing polymer granulates [5,6] with high fill levels [5] and often discharging at high outflow rates [6], are known to honk.

The objective of this paper is to study the particle-wall and particle-particle interaction for two different polymer granulates and two different wall materials. The interaction between particles and the wall material is examined for slip-stick, which can be a possible source of excitation in the silo honking phenomenon. The Jenike shear tester was used to investigate this interaction. Different variations were implemented including normal stress variation and sample size variation. The shear response was recorded and plotted against time and displacement.

2 MATERIALS AND METHODS

Two different pellets were tested – PET and blue polypropylene. Industrial experience suggests that PET pellets honk while polypropylene pellets do not. PET pellets considered were in the shape of flattened cylinder with an elliptic cross-section. The typical cross-section of these pellets was 4x1.5-2 mm with 4 mm height and density was in the range 770-890 kg/m³. The polypropylene pellets were shaped like squat cylinders with 5 mm diameter and 1.5-4 mm height. The density range for these pellets was 550-620 kg/m³. Two different plate materials were considered: aluminium and stainless steel. The aluminium plate had a thickness of 6.1 mm with a roughness average of 0.88. The stainless steel plate was 4 mm thick with a roughness average of 0.5.

The measurements were performed using a Jenike Shear Tester. Most tests were conducted with a shear ring of 143 mm diameter. Shear ring diameters of 95 mm and 63 mm were used to determine sample size effect. To investigate the particles-wall interaction a shear plane was created between the pellets and the plate (Fig. 1). In these tests the shear ring was placed over the plate and filled with pellets. Once the sample was levelled, a cover was placed on top of the pellets and a vertical force was applied to the cover. Shearing was initiated by applying a horizontal load to the bracket under displacement control [7]. To investigate the particle-particle interaction a shear plane was created between the pellets. The procedure was similar to that described above, except in this case a base container filled with pellets replaces the plate. Base container and shear ring were offset on each other and the horizontal force was applied to the bracket of the top shear ring, creating a shear plane between particles [7].

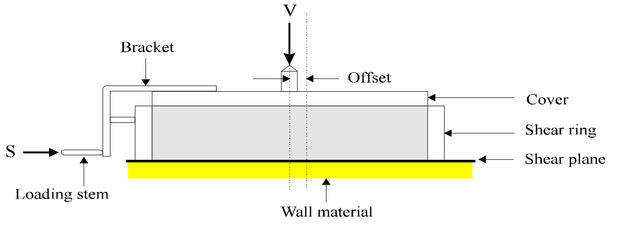

Figure 1: Jenike shear tests for particle-wall interaction.

3 RESULTS AND DISCUSSION

3.1 Effect of stress level and materials

Figure 2 shows the shearing response of PET pellets on the aluminium plate for four different normal stress levels and a shear rate of 1mm/min. The stress levels were chosen to reflect the real conditions in a silo that was known to honk with PET pellets. Considerable slip-stick response, illustrated by fluctuating shear stress, was observed between PET pellets and aluminium plate. The magnitude of these fluctuations increases with normal stress level. The pellets stick against the aluminium plate until a certain magnitude of shear stress is reached. After this a sudden slip occurs, bringing the shear stress down to a lower value. This behaviour is repeated periodically. The same normal stress levels were used with the polypropylene pellets on an aluminium plate and they were sheared at the same rate. The results are shown in Fig. 3. It can be seen that slip-stick fluctuations are absent in this case for all stress levels.

A stainless steel plate was used to perform the same kind of tests with the two pellets. Figure 4 shows the shear response between PET pellets and steel plate. It can be seen that the slip-stick response is present for steel as well. Comparing Figs. 2 and 4 it can be seen that while there is negligible shear stress fluctuation at the lowest stress level considered (5 kPa) for the aluminium plate there is significant fluctuation with the steel plate. Moreover the increase in shear stress fluctuations with normal stress is more gradual with steel in comparison to aluminium. Figures 2 and 4 also show that the typical magnitude of slip displacement of PET pellets is larger for stainless steel than for aluminium. The fluctuation magnitude is also larger with stainless steel. The blue polypropylene pellets were also tested with the stainless steel plate. The results are shown in Fig. 5 and once again exhibit no slip-stick.

By dividing the maximum shear stress value by the normal stress we obtain the maximum wall friction coefficients at different normal stress levels. Similarly the minimum wall friction coefficients can be obtained by using the minimum shear stress values. It was found that the maximum friction coefficients are not influenced by normal stress variations in the PET-aluminium combination. On the other hand, the minimum wall friction coefficients for this combination reduce significantly with increase in normal stress (Fig. 6). For PET–stainless steel combination both, maximum and minimum wall friction coefficients, show a small reduction with normal stress (Fig. 7).

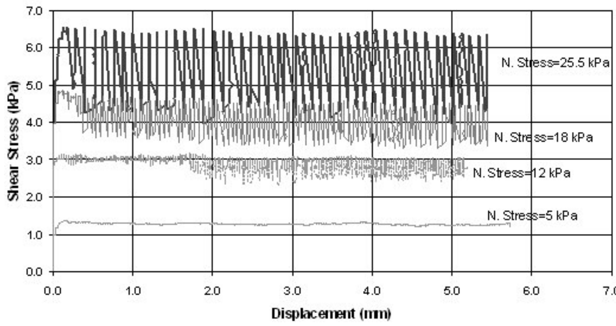

Figure 2: PET-aluminium shearing response.

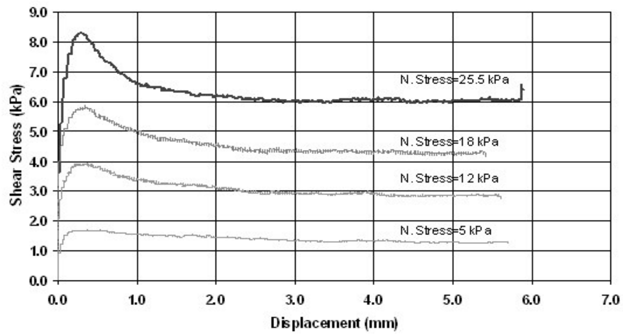

Figure 3: Polypropylene-aluminium shearing response.

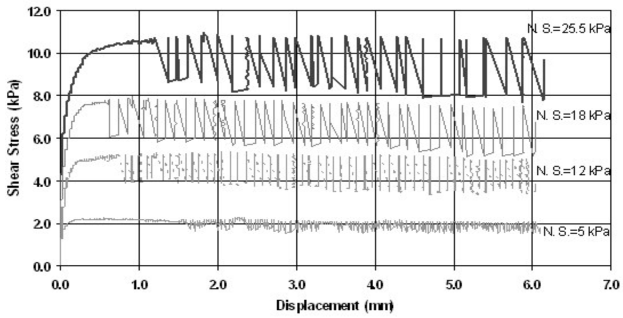

Figure 4: PET-steel shearing response.

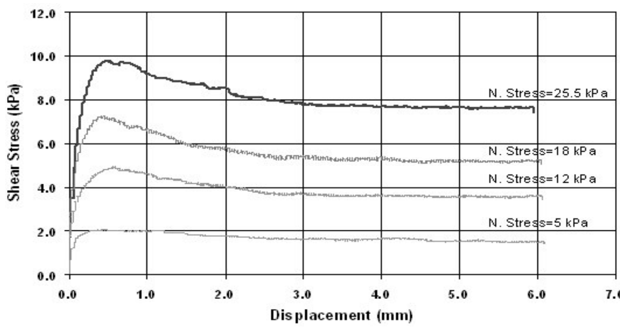

Figure 5: Polypropylene-steel shearing response.

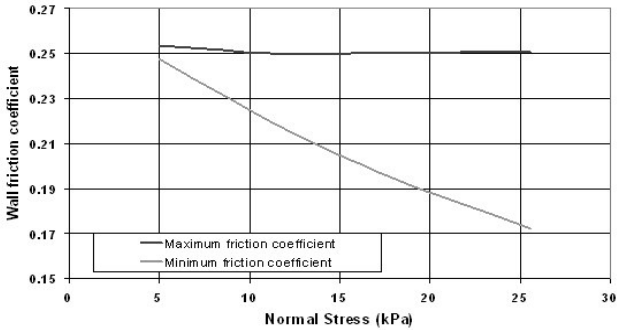

Figure 6: PET-aluminium wall friction coefficient.

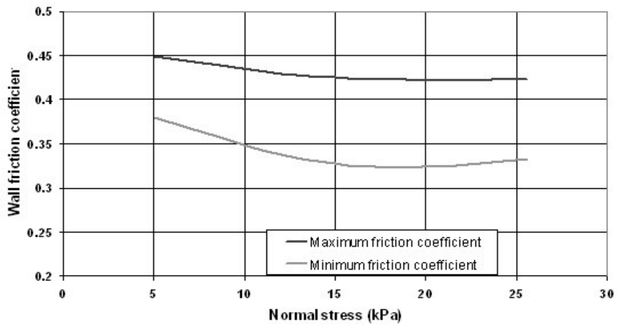

Figure 7: PET-steel wall friction coefficient.

3.2 Slip-stick variation as a function of time

Figure 8 shows the shear stress response of PET pellets on aluminium and stainless steel plates as a function of time for 25.5 kPa normal stress. It can be seen that the frequency of fluctuations for aluminium plate is higher than for stainless steel. Typically in each cycle the duration between the minimum shear stress value to the maximum value (stick zone) is longer in the stainless steel plate than the aluminium plate.

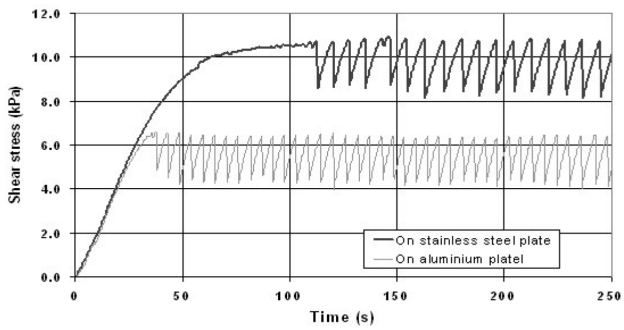

Figure 8: Shearing response as function of time.

3.3 Sample size effect

All the tests described above were conducted with a large ring with 143 mm diameter. To examine the influence of sample size two other ring sizes were included – a standard ring (95 mm diameter) and a small ring (63 mm diameter). It may be noted that for Jenike tests 95 mm diameter ring is standard. Figure 9 shows that for PET–aluminium combination, large slip-stick fluctuations are observed only when pellets were placed in the large ring. The response with standard and small rings is similar and slip-stick is almost absent. In the three tests, the maximum wall friction coefficient is independent of sample size. The normal pressure was then increased from around 25 kPa to about 56 kPa in the standard and small rings. Results are shown in Fig. 10. At this normal stress level, slip-stick response appears in the standard ring sample, but not in the small ring sample. The magnitude of shear stress fluctuations in the standard ring sample is about 3 kPa. The maximum wall friction coefficient reduces slightly from its value at the normal stress of 25 kPa. Further increase of normal stress level (to 126 kPa) in the small ring also showed significant slip-stick fluctuations. This slip-stick dependency on sample size and stress level cannot be readily explained. The same tests were carried out for the blue polypropylene pellets. The behaviour of the pellets was very similar in the three sample sizes. No slip-stick response was observed for any of the ring sizes.

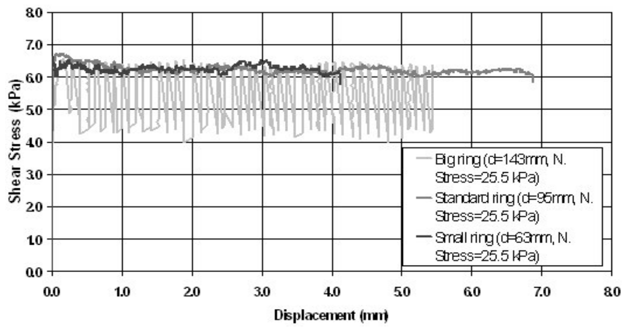

Figure 9: PET-aluminium shearing response for different ring sizes at approximately 25 kPa.

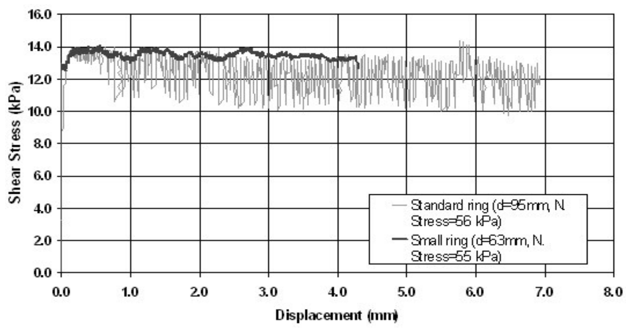

Figure 10: PET-aluminium shearing response for different ring sizes at approximately 55 kPa.

3.4 Internal friction tests

The procedure described in Section 2 for testing particle-particle interaction was carried out for the two pellets. The tests were conducted at a stress level of about 25 kPa. Previous tests on known-to-honk pellets, where normal stress variation has been taken into account, have shown that the slip-stick response between particles is not as cyclic and significant as it is for particle-wall interaction [4,5]. Again, three different sizes of shear rings (large, standard and small) were used. Figure 11 shows that the sample size appears to influence the shear stress response. Intermittent drop of shear stress was observed. The results show that these drops tend to reduce when the sample size increases. Similar tests, using the large, standard and small ring, were conducted for the blue polypropylene pellets. The results are shown in Fig. 12. Intermittent drops in shear stress were less evident for the three different sample sizes. The effect of sample size is less clear for the interaction between particles in both pellets.

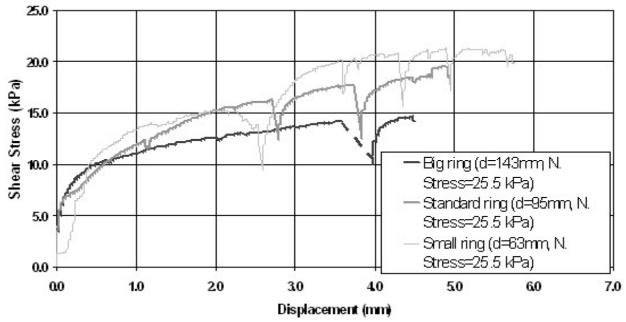

Figure 11: Internal friction response of PET pellets.

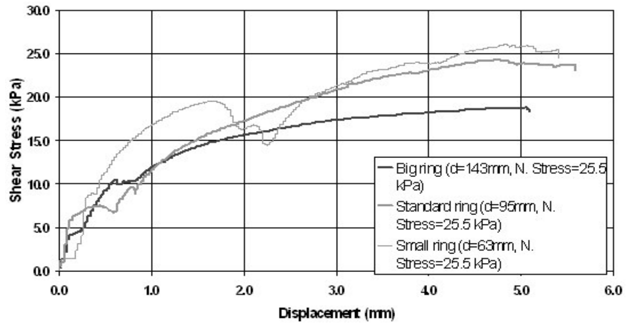

Figure 12: Internal friction response of polypropylene pellets.

4 CONCLUSIONS

The study shows that slip-stick, represented by shear stress fluctuations, is absent when the blue polypropylene pellets are sheared on either aluminium or stainless steel plates. On the other hand shear stress fluctuations are observed with PET pellets for both plate materials. The magnitude of these fluctuations increases with normal stress, indicating these fluctuations would be larger at the lower end of a silo. The magnitude of fluctuations is larger for the stainless steel plate. The maximum friction coefficient for PET–stainless steel is higher than that for PET–aluminium. On the other hand the frequency of fluctuation is higher for PET – aluminium. Stainless steel plate has a longer stick phase. Slip-stick response is also observed with standard and small sample sizes when tested at considerably high normal stresses.

Interaction between PET pellets and wall material (aluminium and stainless steel) is strongly influenced by slip-stick. The slip-stick response between PET pellets and the two metals considered is fairly periodic unlike honking that occurs intermittently [2,4-6]. Slip-stick response was observed to be stress dependent with higher fluctuations at higher normal stress levels. Silo honking too has been reported to occur at high fill levels [5] that induce high stress levels. Silo honking has also been reported to commonly occur at high outflow rates [6]. However, studies suggest that the magnitude of slip-stick fluctuations reduces when shearing rate increases [5,8]. How slip-stick fluctuations lead to honking, if they do, is yet to be fully understood.

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