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An Analysis of the Influence of Cylinder Dimension Ratio and Lifting Velocity on the Slump Test Results

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Abstract:
As a fundamental rheological property, shear yield stress is used to assess the flowability of suspensions. Slump test is a cheap and quick experiment which is commonly used to estimate shear yield stress on-site. It has been generally believed that, cylinder height to diameter ratio and lifting velocity has no effect on the slump test results. In this work, the sensitivity of the slump test to the height to diameter ratio and lifting velocity of cylinder was investigated. Projections on the top surface of suspension column after the slump test were also analyzed. Results indicated that, the effect of cylinder height to diameter ratio is negligible in the low range of shear yield stress, while it is remarkable in the high range. It was deduced that, using a cylinder with dimension ratio in the range of 0.83 to 1.15 is more reliable. Furthermore, it is shown that the lifting velocity of cylinder has a significant effect on the results. A high lifting velocity could introduce a great error in estimation particularly in a large height to diameter ratio.

Key words:
rheology, shear yield stress, slump test, height to diameter ratio, lifting velocity

1 INTRODUCTION

Mineral-separation processes are mostly carried out on suspensions of ground particles of ore in water. Thus, the efficiency of process is affected by rheological behaviour of suspension which is dependent on interparticle forces. Shear yield stress is a rheological property which is defined as the minimum stress required to start flowing of suspension and can be measured using vane rheometer or the slump test in a variety of suspension conditions [1]. In comparison with the vane technique, the slump test is a quick and inexpensive test and can be performed on-site. Chandler [2] modified the slump test to a cylindrical shape. It was shown that, the slump test result using a cylinder rather than a frustum is more reliable [3]. In civil engineering, the slump test is widely used to assess the flowability of concrete [4, 5]. In mineral processing it can be used to determine process efficiency when solids concentration of suspension is relatively high. Baudez et al. [6] modified the slump test for the materials with high shear yield stress by adding a mass on the sample top. In the last decade, the slump test was widely used in studies on thickening [7], tailings disposal [8–10] and characterization of the rheological properties of mineral suspensions [11–13].

The theoretical analysis of slump test was first devised by Murata [14] and then modified by Christensen [15]. Pashias et al. [16] developed the model for cylindrical geometry. Based on the procedure introduced by Pashias et al. [16], a cylinder must be placed on a smooth surface, filled with a suspension sample and then lifted up. With lifting the cylinder, flow of the suspension is started and the top level of suspension moved down. Final height of the suspension column is measured after lifting and the difference between the initial and final state “*S*” is designated as the “slump” height. The shear profile in suspension column is demonstrated before and after a slump test in Figure 1. Pashias et al. [16] stated that, as the cylinder is lifted up (Figure 1a), the suspension starts flowing and spreads out (Figure 1c), because the shear in the lower section

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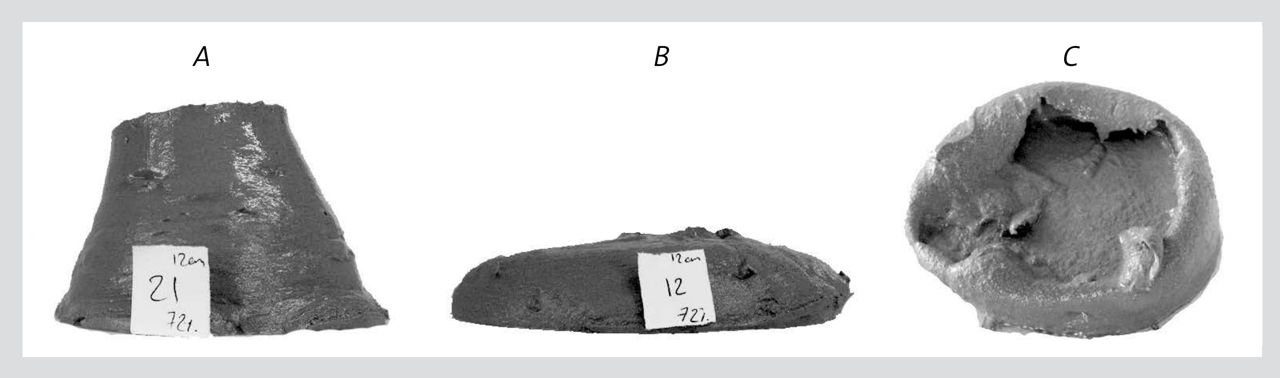

Figure 8: The pictures of suspension column after slump tests with 72 %wt solids concentration using a cylinder of 12 cm height with low (A) and high (B) lifting velocity (side view) and (C) using a cylinder of 2 cm height with high lifting velocity (top view).

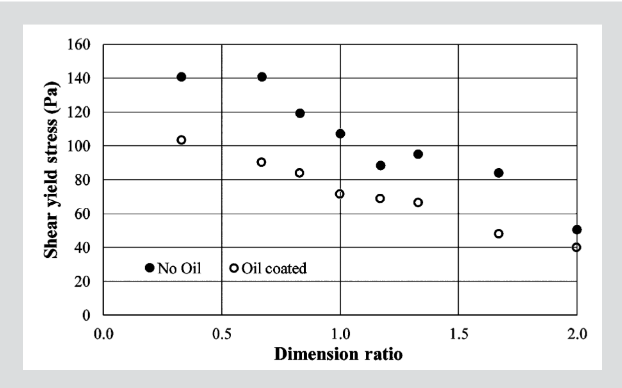

Figure 9: The effect of the oil coated cylinder on the results of slump tests with high lifting velocity (solids concentration of 72 %wt).

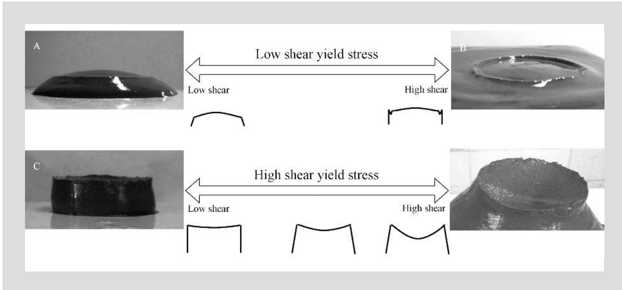

Figure 10: Four main categories of the top surface features of suspension after slump tests with low and high shear (66 and 72 %wt solids concentration).

As can be seen from Figure 9, the shear yield stress obtained with a high lifting velocity was significantly reduced due to decreased friction with the greasy cylinder. Whereas, Saak et al. [18] found that with a low lifting velocity the effect of oil coated surface was not significant. Generally, it is recommended to lift the cylinder gently during the slump test to minimize the dynamics effect of lifting on the results. With a comparison between Figures 4 and 9 it can be inferred that, in the case of oil coated cylinders, differences between the results of slump tests with high and low lifting velocities would be more considerable. With the impact of the cylinder surface friction on the results, it can be deduced that the surface material of cylinder (e.g. PVC, glass or steel pipe) is also influential on the obtained shear yield stress. It is notable that, initially with the cylinder being located on the surface, the velocity of lifting is zero. Hence, the slump test results ought to be attributed to the acceleration of lifting.

3.7 ANALYSIS OF PROJECTIONS ON THE TOP SURFACE OF SUSPENSION

In the development of Pashias et al. [16] model, it was assumed that, every horizontal section in suspension remains horizontal during the test. In this work, the top surface feature of suspension after lifting was studied. The resulted features can be divided into four main categories (Figure 10). Pictures in Figure 10a and b were taken of the top surface of suspensions after tests with 66 %wt solids concentration (2 and 18 cm height cylinders). As can be seen from Figure 10a, the outer layers of suspension moved down, while the central part of suspension column appears not to be affected by the vertical shear due to lifting the cylinder. Figure 10b shows that, a circular projection appeared on the periphery of the suspension column, while the inner area was moved down. Based on the visual observations using a camcorder, downward movement of the inner area started at the initiation of lifting the cylinder. As the test initiated, the outer layer of suspension moved upward and the adjacent inner portion displaced the lower elements of the outer layer. Difference between the levels of the outer and inner layers was increased using higher cylinders. With a comparison of Figure 10a and b it can be said that, different cylinder heights cause different levels of shear in the vertical direction resulting in varying shapes of the top surface. The central part of suspension column appears not to be affected by the vertical shear which can be considered in the calculation of the shear yield stress. It is worth noting that, the top surface features such as shown in Figure 10a and b could be resulted at the beginning of the paste behaviour of suspension.

With a higher solids concentration, the movement of suspension is more limited due to a higher shear yield stress. Pictures in Figure 10c and d were taken after the test with 72 %wt solids concentration suspension (2 and

18 cm height cylinders). As can be seen in Figure 10c the upper surface due to a low shear caused by a low cylinder height, is almost horizontal which is considered desirable leading to an acceptable error. As is shown in Figure 10d, with increasing cylinder height and shear rate in suspension the edge of suspension column moved upward and reached a maximum level (7 mm above the central part) corresponding to the maximum shear with the 18 cm height cylinder, which could be the result of a solid like material being formed due to a high level of interparticle forces. From Figure 10c and d, it is suggested that, the height of the center of suspension be considered in the calculations of slump test.

4 CONCLUSION

With the aim of limiting the variables to the suspension being tested, the effect of the cylinder dimension ratio and lifting velocity on the slump test results was investigated. Results show a significant relationship between the high range of shear yield stress obtained and cylinder dimension ratio. The results in cylinder dimension ratio of 3 deviate from those obtained with other dimension ratios. In high shear yield stresses, this was caused by bending of suspension column, while in low shear yield stresses due to downward movement of suspension a higher slump height was resulted. It was found that, lifting velocity has a remarkable effect on the results of slump tests particularly in high shear yield stresses. Increasing the dimension ratio of cylinder will lead to intensify the effect of lifting velocity and in particular cases the destruction of the remained suspension. It was deduced to use a cylinder with dimension ratio of 0.83 – 1.15 in slump tests. In addition, it was shown that cylinder surface properties has a significant effect on the results. Moreover, the sensitivity of the final height of suspension is less than dimensionless slump to dimension ratio and it seems more reliable to be used in the calculation of shear yield stress.

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