

Smaller specimens were to be used to overcome the problem of one specimen per test. Apart from the time problem of one specimen per test, it was also difficult to maintain constant flow conditions, especially particle size. Thus the specimen holder was designed to hold 7 specimens of 10mm X 50mm X 5mm thick, including a 10mm wide mild steel protective rim (Figure 29, Pg 63). The protective rim was screwed into the backing plate and the specimens secured with double sided tape, which facilitated removal.

Initial tests to determine the feasibility of this specimen configuration revealed that a wear profile existed across the samples. Thus this testing configuration had to be tested to establish whether each specimen was going to be subjected to the same conditions within the pipe ie. did horizontal or vertical wear profiles exist within the pipe due to particle or velocity concentrations across the pipe?

Tests were conducted with middle of the range conveying conditions to optimise the following:

- * Orientation of samples ie. vertically or horizontally placed on the sample holder
- * Impact angle
- * Repeatability

These tests were conducted using mild steel samples, so that any difference in wear rates from sample to sample could only be attributed to the factors mentioned above, and not to the material.

Once the optimum orientation and impact angle had been established for mild steel, these conditions were tested using tungsten carbides of the same grade.

5.1 Effect of orientation of sample on wear

5.1.1 Vertical wear profile

The mild steel samples were inserted with the major axis parallel to the direction of flow i.e. horizontally. This established that there was a wear profile vertically across the pipe as illustrated in figure 31, Pg 66. The maximum difference in wear rates under these conditions was 38.4%. This follows the generally accepted theory that there is a particle concentration and/or velocity gradient across the cross section of a horizontal pipe, and therefore one can expect that a wear gradient does exist.

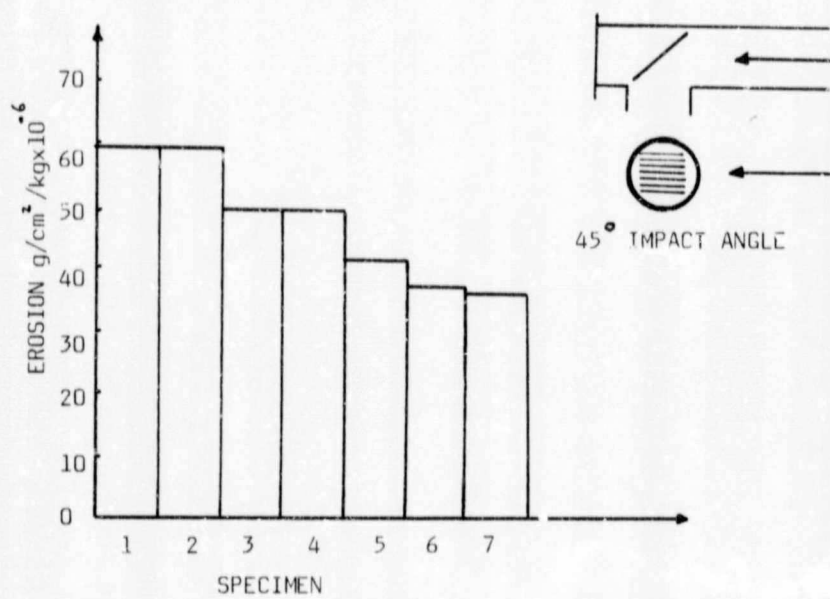


Figure 31. Results of preliminary wear tests at 45° impact angle showing a vertical wear gradient across the pipe.

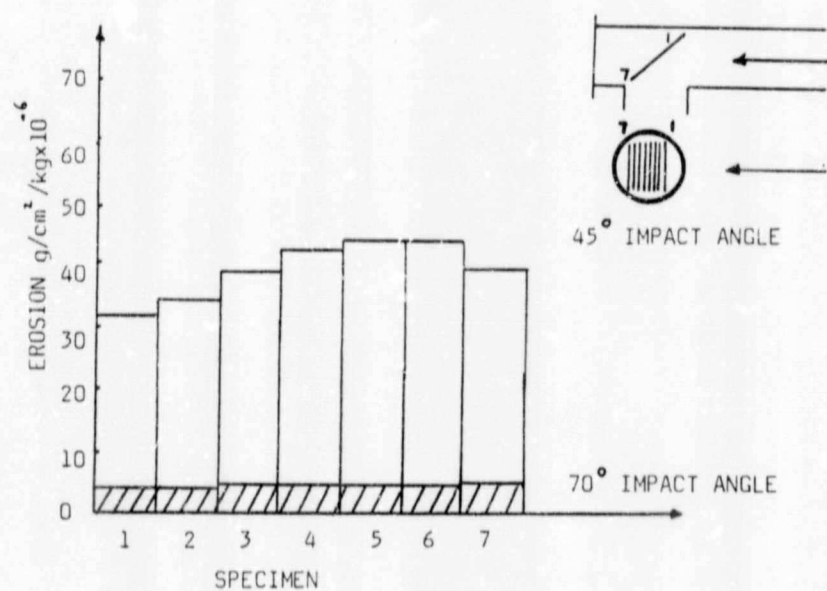


Figure 32. Results of preliminary wear tests at 45° and 70° showing the horizontal wear profile across the pipe.

From this information it was decided to keep the test specimens vertical so that each specimen would be exposed to the same vertical wear gradient.

5.1.2 Horizontal wear profile

When the specimens were orientated vertically, the wear rate was also variable, although not as much of a pronounced profile was observed compared to the horizontally orientated specimens. (The maximum difference in wear rates in this case was 29%).

From these sets of tests, (vertically and horizontally mounted specimens) it was established that all specimens in future tests should be mounted vertically because the error was less.

However, the optimum testing angle had still not been established, but it can be seen that at 70° (Figure 32, Pg 67, lower bar graph) for vertically mounted specimens, the wear rate was much reduced, and this prompted further investigation to find the optimum testing angle.

5.2 Effect of Impact Angle

Tests using mild steel specimens were conducted at 51° , 70° and 90° to the flow vector to establish the optimum impact angle to conduct the tests.

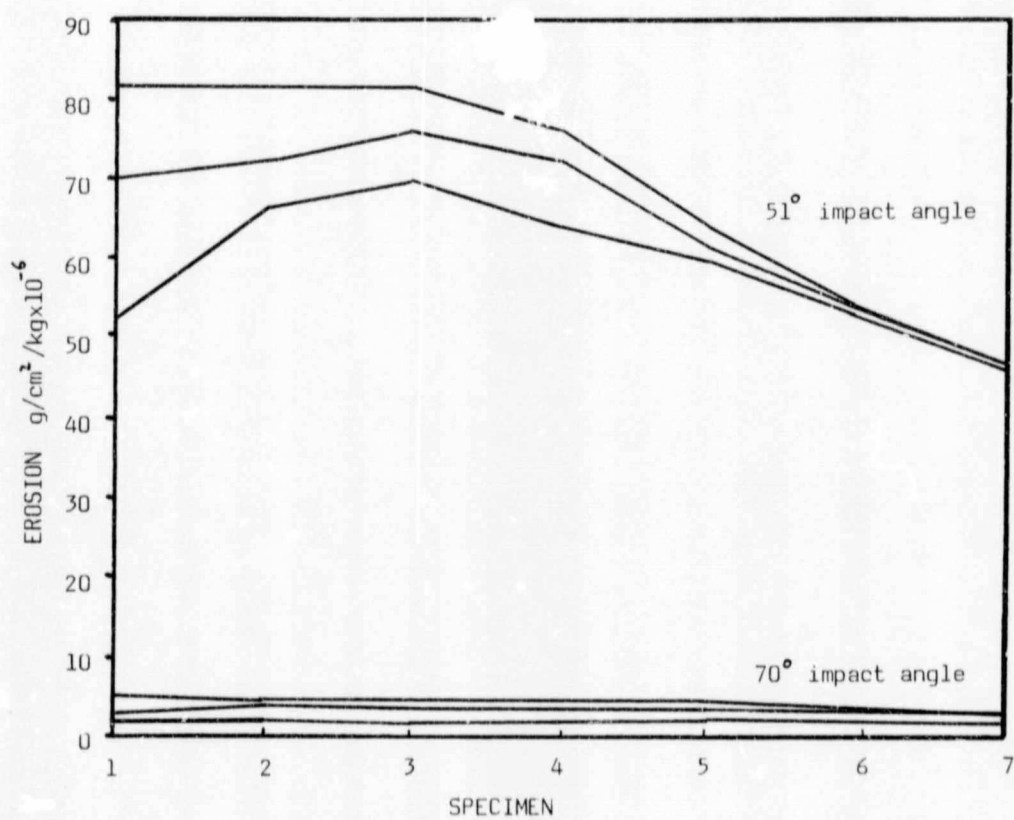


Figure 33. Graph showing the results of the impact angle tests at 51° and 70° for mild steel.

From Figure 33, Pg 69, it can be seen that the wear profile is less pronounced at higher angles of impact, although the error range between samples is high in both sets of angles ie:

At 51° the maximum difference in wear rates was 26%

At 70° the maximum difference in wear rates was 21%

There appears to be an approximate eight-fold increase in wear at the lower angle of impact.

Tests conducted at 90° showed no wear at all, as well as very little surface damage. This was attributed to the sand packing against the specimens and forming a protective barrier.

To keep the error to a minimum, it was thus decided that the optimum testing configuration should be to orientate the specimens vertically and mount them at 70° to the flow vector.

Figure 33, Pg 69, also gives an indication of the repeatability of the tests. (Each line corresponds to one test). It can be seen that even though the error is of the order of 20%, the tests for each set of conditions (in this case impact angles of 51° and 70°) fall into distinct "error bands", and therefore discernible results and conclusions could be extracted.

Examination of the specimens after the tests revealed that at lower impact angles, the resultant surface profile of each specimen tended to be rounded off, and a lip formed over the next specimen. These observations prompted the testing of this configuration using complete mild steel plates instead of 7 individual specimens. This would show if the surface profile was real or if it was a result of edge effects. These results are documented in Appendix D.

5.4 Repeatability tests using WC-Co

Having established the optimum testing configuration using mild steel, a set of tungsten carbide specimens was then used to evaluate their performance using this configuration. Tests were conducted using the same conveying conditions, at impact angles of 51° and 70° .

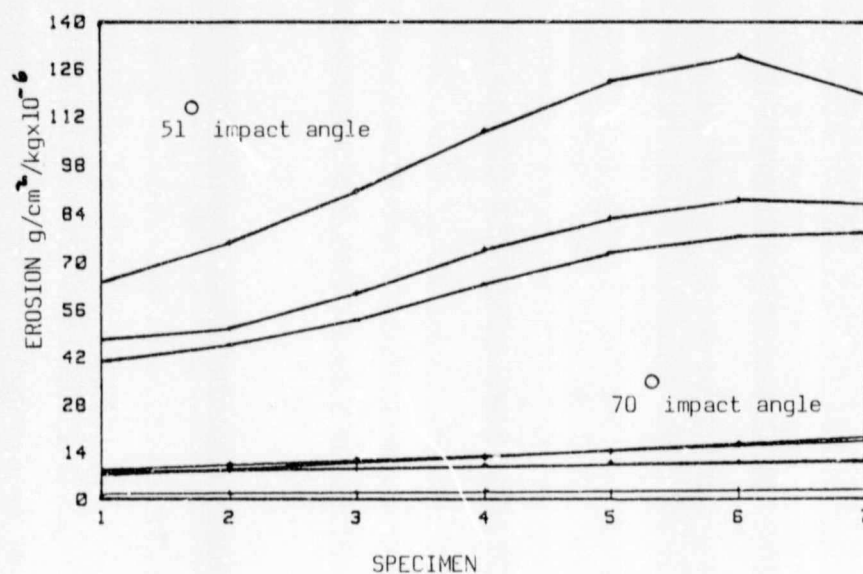


Figure 34. Graphs showing the results of the repeatability tests using WC-Co specimens at 51° and 70° .

The tests were repeated three times at each angle under the same conditions, using the same sand. It can be seen from figure 34, Pg 71, that the wear at 51° is much higher than at 70° , which is contrary to the expected erosion of WC-Co.

As can be seen there is a definite profile across the specimens at 51° compared to the tests at 70° whose profile appeared quite "flat". It is interesting to note that this profile is in the opposite direction to mild steel (Figure 33, Pg 69), and can possibly be explained by the fact that the two materials have completely different eroding mechanisms.

5.5 Conclusion

This series of tests using mild steel and tungsten carbide indicated that the "best" testing configuration was using vertically placed specimens at an impact angle of 70° for the influence of velocity and solids mass flow rate (because even though there was gradient, it was flatter than the gradient at 51°).

The influence of impact angle would then be tested in a separate set of tests.

6 Method of Experimentation

6.1 Experimental Procedure

The specimens were to be tested under the following conditions:

- Constant solids mass flowrate, changing velocity
- Constant velocity, changing mass flowrate or phase density
- Constant velocity and solids mass flowrate, changing impact angle

By virtue of the fact that a range of WC-Co alloys was present in every test, effect of grain size and Co content could be tested for each of the abovementioned conditions.

The conditions were obtained as follows:

A state diagram for this particular pneumatic conveying system was obtained without any samples in place. The state diagram was generated by choosing various combinations of compressors and then changing the solids mass feedrate for this particular air mass flowrate. Three compressor combinations were used to indicate the extremes of the testing 'grid' that could be used. This state diagram then served as a basic guideline for the operating settings required to obtain constant solids mass flowrates etc.

The influence of impact angle was determined by choosing one suitable point on the state diagram, all parameters except impact angle could then be kept constant.

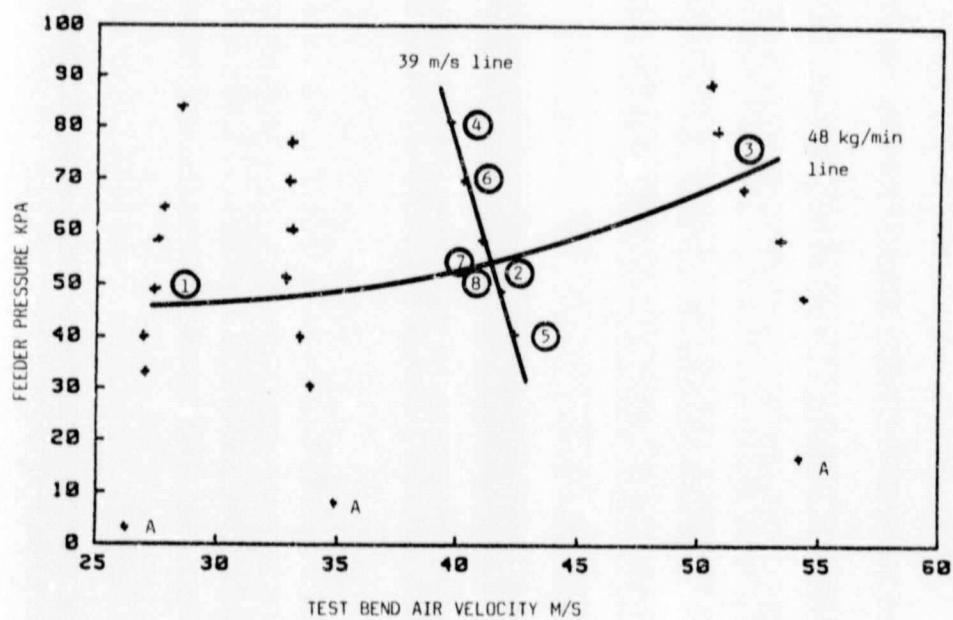


Figure 35. State diagram for wear rig showing the chosen testing points.

Figure 35 was generated as follows (corresponding to the theory illustrated in figure 1, Pg 11):

- * A combination of compressors was used to generate a particular air velocity. Four different compressor combinations were chosen so that the air velocities ranged from approximately 28 m/s to 53 m/s. These four velocity ranges can be seen above on figure 35 as relatively vertical lines.

- * For each velocity range, a solids mass flowrate was established by incrementing the PID index pressure by 10 kpa intervals from 30 kpa to 90 kpa. For each pressure setting a solids mass flowrate reading was taken.
- * Once all four velocity ranges and their associated solid mass flowrates had been established, the constant solid mass flowrate lines could be drawn in diagonally across the state diagram.

As can be seen from figure 35, Pg 74, a suitable constant solids mass flowrate line was chosen (48 kg/min), so that this solids mass flowrate could be obtained well within the range of velocities obtainable. Effect of velocity could thus be obtained along this line. Three operating points were chosen "horizontally" across this line (corresponding to a particular set of compressors) and the PID pressure settings read off the state diagram.

A constant velocity line was then chosen, to facilitate effect of solids mass flowrate tests. This is not a truly constant velocity line as the velocity decreases slightly for increased mass flowrates, but it was sufficient for the purposes of the experiment. Four test points were chosen along this "vertical" line.

The conditions corresponding to the crossing point of these two chosen lines were used for the impact angle tests as one point had already been generated.

The following two test matrices summarise the manner in which each conveying parameter was tested ie. effect of air velocity, solids mass flowrate and impact angle, as well as each material parameter.

6.1.1 PNEUMATIC CONVEYING TEST MATRIX

(These testing point numbers correspond to the circled numbers on figure 35, Pg 74).

<u>TESTING POINT</u>	<u>PARAMETERS</u>
1,2,3	<u>Variable velocity tests</u> (28.72m/s, 39.51m/s, 51.82m/s) Constant solids mass flowrate (46 kg/min) Constant impact angle (70°)
2,4,5,6	<u>Variable solids mass flowrate tests</u> (35.44kg/min, 46.05kg/min, 64.24kg/min, 83.40kg/min) Constant velocity (39m/s) Constant impact angle (70°)
2,7,8	<u>Variable impact angle tests</u> (30°, 50°, 70°) Constant solids mass flowrate (64kg/min) Constant velocity (39m/s)

Three tests were conducted at each point to check repeatability. Not enough samples were available for each test to be started with a new sample. The same samples were used until the height differential from sample to sample on the testing plate became too great.

6.1.2 MATERIAL TEST MATRIX

The materials to be tested were a range of tungsten carbides against a mild steel standard. The cobalt content and grain size of the tungsten carbide alloys are summarised as follows in table 1:

(See Appendix E for detailed characteristics)

% Co	GRAIN SIZE			
	fine		course	
	.5 microns		2-3 microns	
6	FF6 F6	M6	C6	
10				
15			C15	
30			C30	

Table 1. Test matrix of tungsten carbide alloys showing the cobalt content and grain size ranges.

The nomenclature is as follows:

FF6	Ultrafine grained 6% cobalt (wt%) alloy
F6	Fine grained 6% cobalt (wt%) alloy
M6	Medium size grained 6% (wt%) alloy
C6	Coarse grained 6% (wt%) alloy
C15	Coarse grained 15% (wt%) alloy
C30	Coarse grained 30% (wt%) alloy
MS	Mild steel

All tests were conducted using 4 mm nominal diameter crushed granite rock as the erodant.

6.2 Test procedure

6.2.1 Sample preparation

The samples were cleaned with acetone, dried, weighed, and then attached onto the specimen holder (See figure 36 below), using double sided tape. The mild steel specimen had to be screwed onto the holder from below to prevent it lifting off the holder and forming a lip over the WC-Co specimens. The specimen edges were protected by mild steel strips, which were also screwed into the specimen holder. (See also figure 29, Pg 63).



Figure 36. Photograph of specimens mounted on the specimen holder.

The angle of the specimen holder was checked and the holder was then inserted into the test bend.

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Figure 36. Photograph of specimens mounted on the specimen holder.

The angle of the specimen holder was checked and the holder was then inserted into the test bend.

After the test had been run, the samples were removed from the test bend, making sure that the impact angle had not changed during the test, and that any samples or edge protectors had been removed. The samples were then cleaned in acetone, dried, weighed and reinserted onto the specimen holder, except for the mild steel specimen which was replaced for each test.

6.2.2 Running of test

- 1) New sand was continually added to the system in order to maintain at least 1.5 tonnes of sand in the system at any one time.
- 2) The load cells were zeroed.
- 3) The pressure setting of the PID controller was set so that the required solids mass flowrate would be attained.
- 4) All pressure transducer filters were emptied to prevent any blockages.
- 5) The correct air routing system from the compressors was chosen and the required combination of compressors switched on.
- 6) The PID controller was then activated and allowed to stabilise at the required pressure and solids mass flowrate setting.
- 7) The computer was then activated to take a set of readings at a predetermined time interval, depending on the length of the test.
- 8) The feeder hopper was refilled just before it emptied completely. This was done to ensure a constant solids mass flowrate.

- 9) The feeder pressure was monitored continually and adjusted manually if the need arose.
- 10) The weighing hopper was emptied once during the test to allow a total of about 3 tonnes to be conveyed.
- 11) On completion of the test, the data was stored on stiffy disks and the relevant graphs plotted to indicate which data points should be chosen for the averaged results.
- 12) The relative heights of the samples were checked between each test. The samples were ordered according to cobalt content (effectively hardness) ie. the 6% cobalt alloys, followed by the 15% and 30% cobalt alloys followed by mild steel. This was done in order to keep the height differential of the samples to a minimum.

7 RESULTS AND DISCUSSION

7.1 Influence of pneumatic conveying parameters

7.1.1 Influence of air velocity

All specimens were tested at three different air velocities, namely 28 m/s, 39 m/s and 52 m/s. All test results have been adjusted so that it is the normal component of velocity to the surface that is considered (30). Figure 37, Pg 83, shows the results of erosion versus velocity in log-log form. An increase in velocity causes an increase in erosion. Further, the effect of cobalt content on the erosion resistance is evident; an increase in cobalt content causes a decrease in erosion resistance. If one considers the 6% cobalt range only (bottom four lines of figure 37, Pg 83), the significant difference in erosion resistance is between the ultrafine grained alloy and the group of fine, medium and coarse grained alloys. The erosion resistance difference between the latter three alloys is discussed in section 7.5, Pg 109, Effect of plastic deformation.

It can also be seen that the gradients of all the lines are virtually the same. This implies that the rate of increase in erosion per unit increase in velocity (effectively energy input) is the same for all the materials. It is thus the Y-intercept that determines the erosion resistance of a particular material, the lower the Y-intercept, the higher the erosion resistance, or rather the higher the "activation energy" required to begin the erosion process.

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