

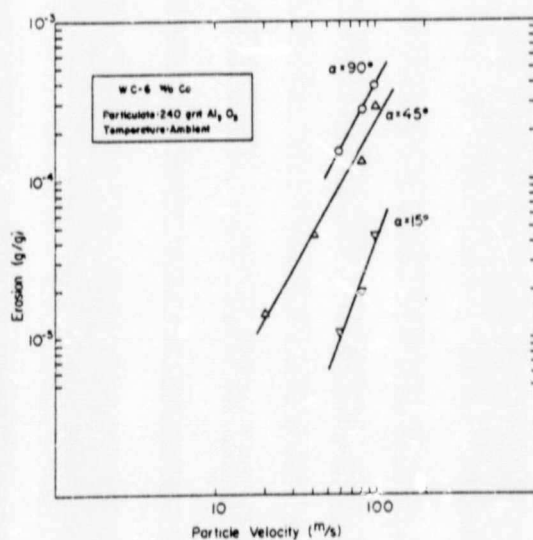


Figure 17. The effect of particle velocity on the erosion of a WC 6 wt % alloy as a function of impingement angle. (After Conrad, McCabe and Sargent, 27)

Angle of impingement

Conrad et. al. (27) found that the angular dependence of the erosion rate depicted in figure 18, Pg 47, was the same for the 6% and 10.5% cobalt content alloys. They found that the maximum erosion rate occurred at 90° . However, it must be noted that high cobalt content specimens were not tested.

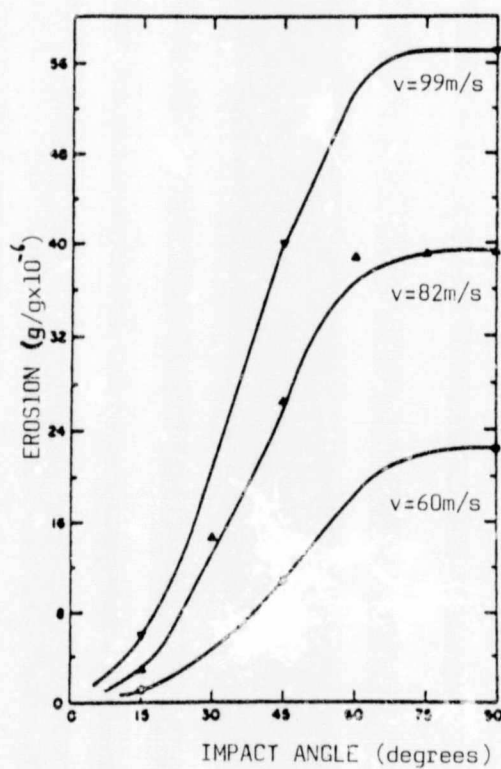


Figure 18. The effect of the angle of particle impingement on the erosion of WC 9 wt% Co alloy as a function of particle velocity. (After Conrad, McCabe and Sargent, 27)

Effect of particle size

Anand et. al. (28), found that the angle of impingement for maximum erosion does not necessarily occur at 90° , depending on the conveyed particle size. Figure 19, Pg 48, shows that the angle for maximum erosion can decrease to as low as 45° , depending on the relative sizes between the particles and the tungsten carbide grain size.

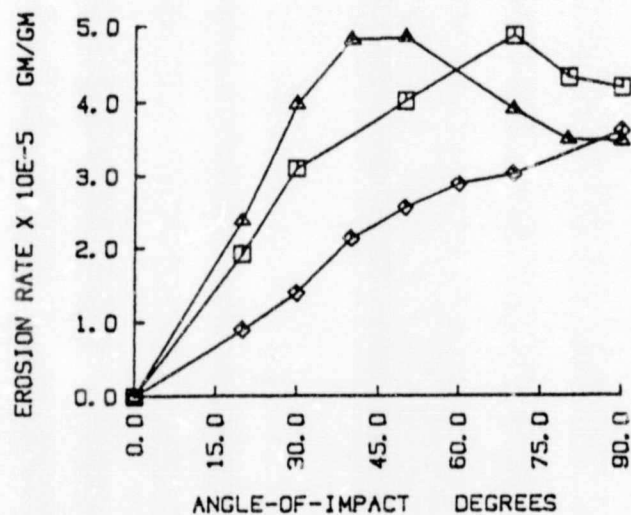


Figure 19. Erosion versus impingement angle. $V=50\text{m/s}$.
 Diamonds = 60 micrometers
 Squares = 140 micrometers
 Triangles = 270 micrometers
 (After Anand et al, 28)

The explanation of this phenomenon is that if the scale of the erosion damage event is varied such that it is large or small relative to the microstructural scale, then the erosion response of the material can be either ductile or brittle. Figure 20, Pg 49, illustrates that if the impact event is large (large particles) compared to the tungsten carbide grain size (figure 20b), then the erosion response can be ductile and hence a decreased impingement angle for maximum erosion. Conversely, if the impact event is small relative to the tungsten carbide grain size, then a brittle type of fracture becomes predominant.

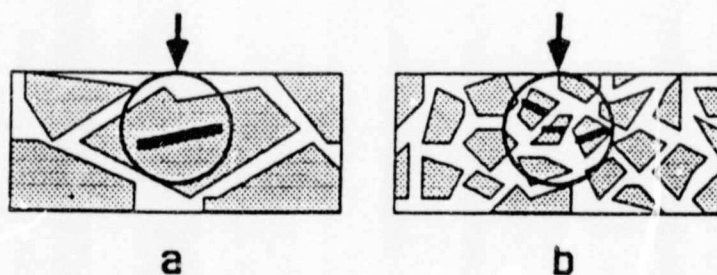


Figure 20. Schematic of the impact event size versus microstructural scales. The dark circles denote the size of the impact events. The dark lines denote cracks in the WC-Co phase. (After Anand et al, 28)

Phase density

No detailed work on the effect of the conveying phase density can be found in the literature.

2.5.5 Modes of material removal

It is generally accepted that tungsten carbide is eroded by the preferential removal of the soft binder phase (cobalt) followed by the fracture and/or extraction of the tungsten carbide grains. It has been shown by Bartolucci et al (29) that this intercrystalline fracture of the tungsten carbide is preceded and initiated by plastic deformation.

2.6 CONCLUSION

From the preceding sections on pneumatic conveying, erosion of pipe bends, properties of tungsten carbide and the erosion of tungsten carbide, a thorough analysis of the relevant theory necessary to support the objectives of this research work has been presented: the objectives of this research being to establish initially whether or not tungsten carbide cobalt alloys are suitable materials to be used to reduce the wear of pipe bends in pneumatic conveying systems.

3 DESCRIPTION OF WEAR TEST RIG

The rig used to test the tungsten carbide specimens is a full size pneumatic conveying system which was initially designed to convey rocks of up to 80 mm diameter. A detailed description of the test rig follows.

3.1 Hopper system

The following description refers to figure 21, Pg 52. There are four hoppers incorporated into this rig. The top hopper, hopper 1, is the hopper where the sand is collected and weighed intermittently after being conveyed. Hopper 2 is a storage hopper while hoppers 3 and 4 are smaller feed hoppers.

Initially sand is fed into the rig through a funnel in hopper 2. Once the rig is running, the sand is stored in hopper 1. The sand flows from hopper 1 through hopper 2 into either hoppers 3 or 4, depending on the position of the flap valve situated just below hopper 2. If hopper 4 is being filled, hopper 3 will be allowed to empty onto a vibrating feeder which feeds the sand into the pneumatic conveying system at a constant feedrate. Similarly, if hopper 3 is being filled, hopper 4 will empty onto the vibrating feeder. The sand is pumped through the pipeline and back into hopper 1.

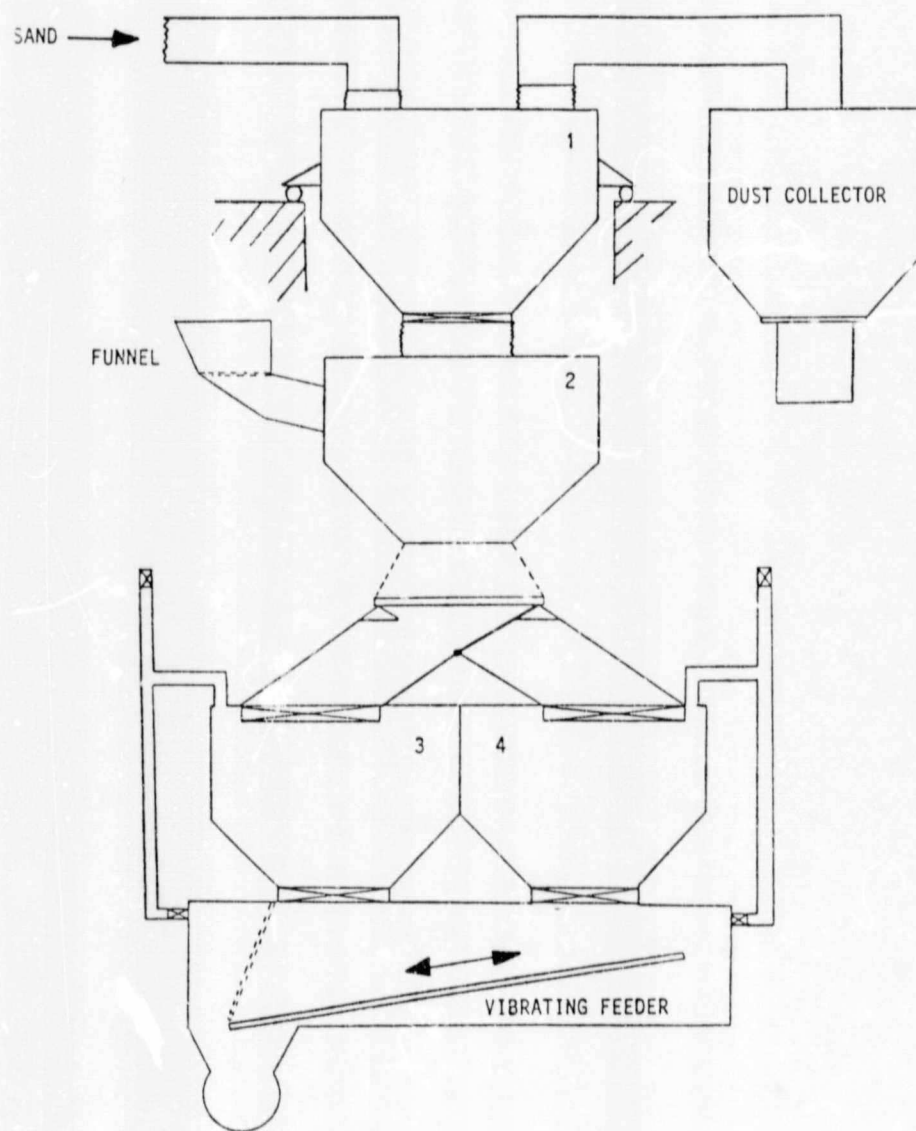


Figure 21. Schematic of hopper feeding system.

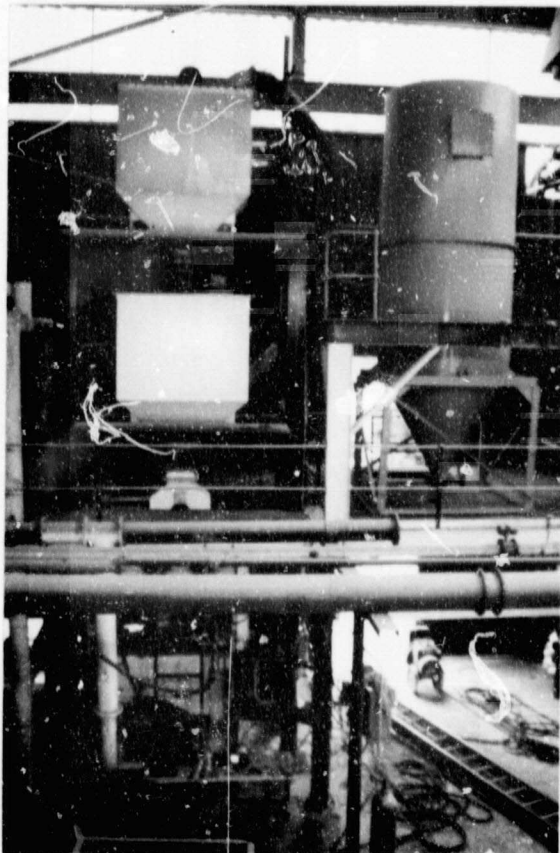


Figure 22. Photograph of hopper feeding and filter system.

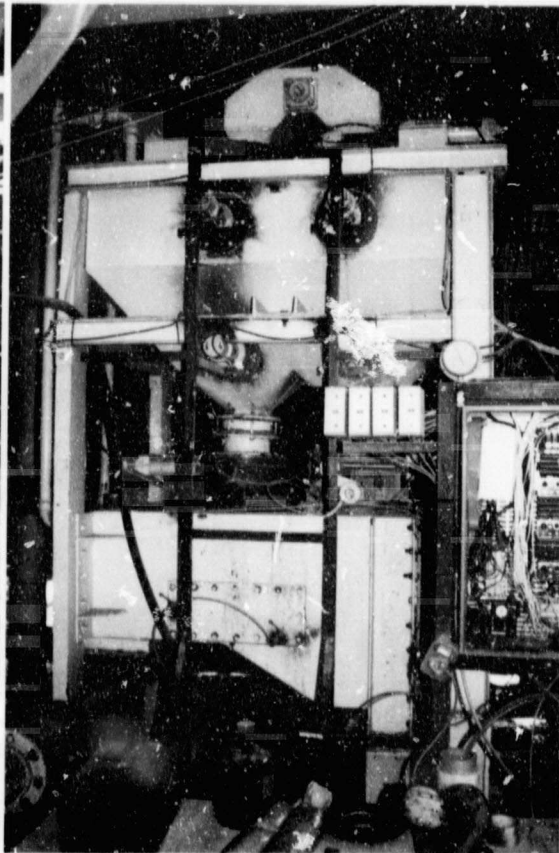


Figure 23. Photograph of vibratory feeder.

3.2 Pipeline

The pneumatic conveying pipeline consists of a horizontal section and a vertical section. There is a minimum of five metres between each bend to allow the flow to stabilise before the next bend is reached. All the pipes are standard 100mm diameter pipes. Tee-bends were used at each bend. Tee-bends as opposed to radiused bends were chosen because of their reduced replacement rate and hence lower cost.

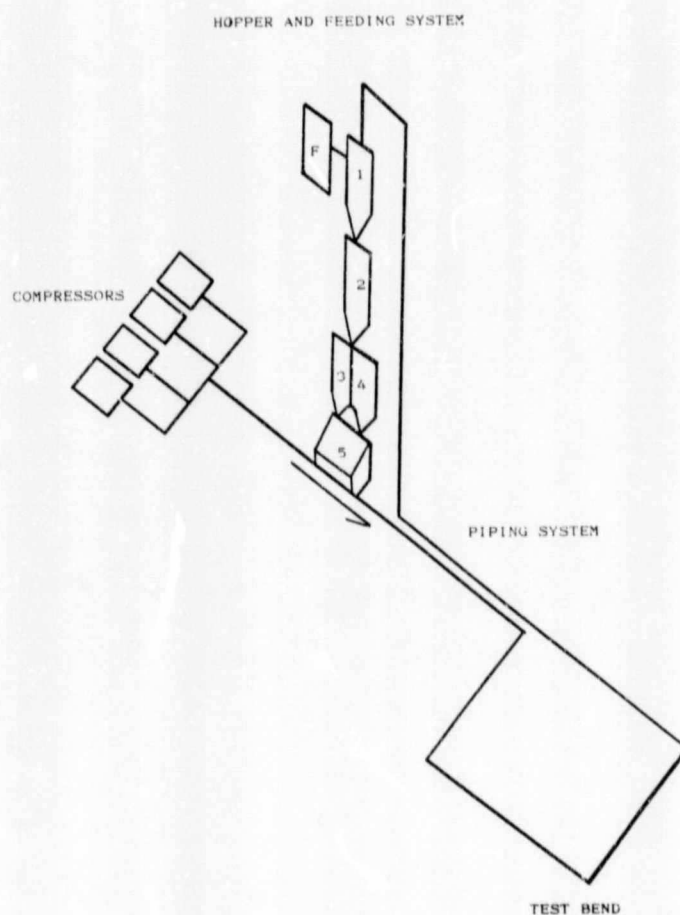


Figure 24. Schematic of complete conveying rig.

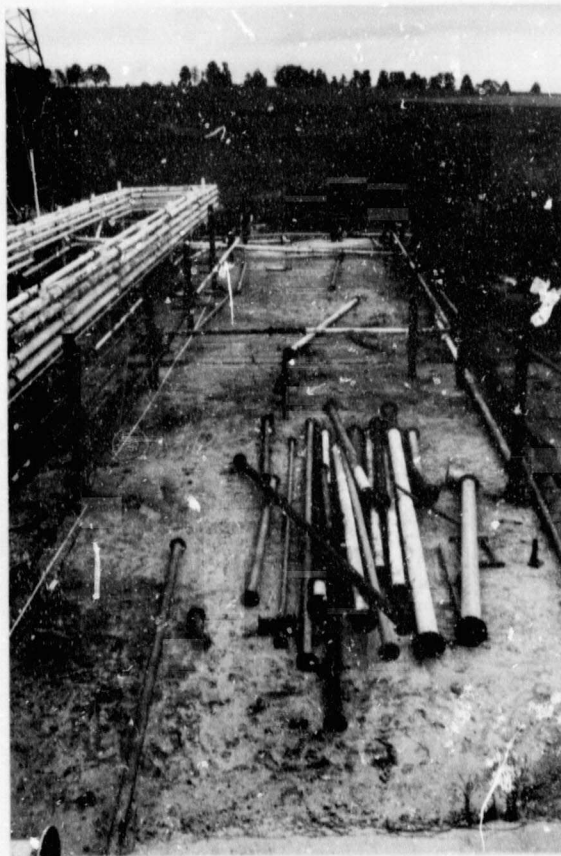


Figure 25. Photograph of pipeline system.

3.3 Prime mover system

The prime moving system is a set of compressors situated in a compressor house, and linked to the test rig via a series of airlines and headers. The piping system is designed in such a way that various combinations of compressors can be used to attain different air flowrates. The mass flow rate of air ranged from 7 kg/min using one compressor, to 40 kg/min using 4 compressors.

4 Development of instrumentation and commissioning of test rig

A complete instrumentation system (including software) had to be developed, installed and calibrated, so that all relevant data for suitably describing the pneumatic conveying parameters of the tests could be recorded. All data was recorded electronically using a data logger, and stored on floppy disk. The instrumentation includes (See Appendix A):

- * 1 Annubar flowmeter mounted in incoming air line
- * 1 thermocouple mounted in incoming air line
- * 1 incoming airline pressure transducer
- * 1 PID controller mounted in feeder control panel
- * 1 feeder pressure transducer mounted in feeder control panel
- * 6 pressure transducers mounted at each bend in the piping system.
- * 1 set of three load cells mounted under hopper 1

4.1 Control system

The test rig, as it stood before the project was started, did not have any sort of control system to keep the system stable while running. This meant that the feed rate had to be controlled manually to keep the feeding pressure constant. This was not satisfactory as a constant feed rate could not be attained.

It was decided to install a proportional-integral-derivative (PID) controller into the feeder control panel which would automatically keep the feed rate constant for a set conveying pressure. The PID controller works by continually adjusting the feed rate (vibratory feeder) from a signal from a feedback loop

from the actual vibrator in the feeding system. For example, if the required pressure was 50 kpa, this would be entered into the PID controller. The PID controller would then increase the feed rate until the actual feeder pressure was 50 kpa. If the actual pressure crept above 50 kpa, the feed rate would be decreased slightly to compensate, and visa versa.

Figure 26 illustrates the consistency of the PID controller in controlling the solids mass flowrate. One can discern the increase in slope of each line as a higher feeder pressure is set.

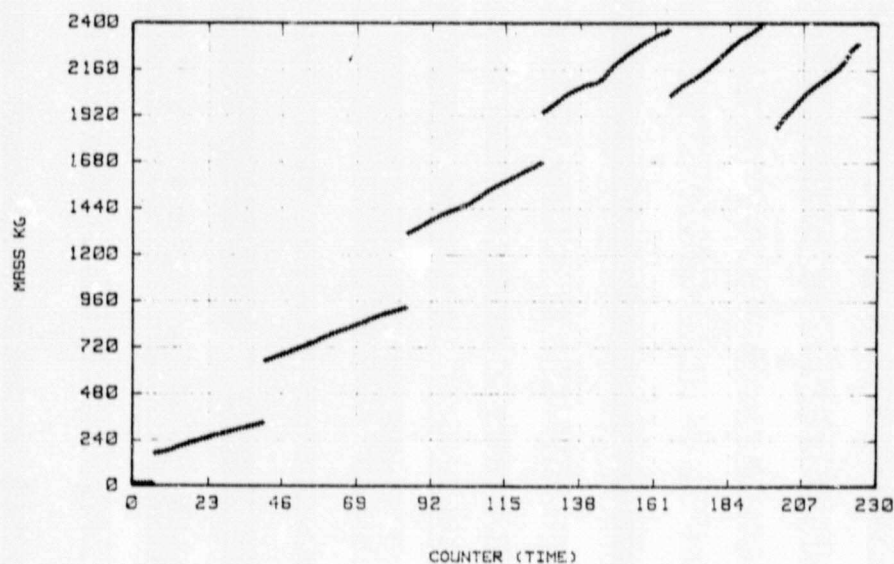


Figure 26. Example of graph of solids mass flowrate. This corresponds to the mass flowrates used to generate the state diagram for the system (See figure 35, Pg 74).

The PID controller was able to keep the feed rate constant as well as maintain the pressure to within ± 10 kpa of the set pressure, which was acceptable.

4.2 Bend pressure monitoring

Six pressure transducers were mounted in the centre of the piping system so that the pressures and hence air velocities could be measured at each bend. Pressure tapping points at each bend were installed, filters fitted and 6mm plastic pressure tubing connected to the pressure transducers. A transducer was also connected to a tapping point along a straight section of the pipeline, in order to be able to develop a pressure drop per straight metre relationship as well as a pressure drop per bend relationship.

4.3 Flowrate measurement systems

4.3.1 Air flowrate

The Annubar flowmeter was already installed, but no calibration curves were available for it. For accurate mass flow measurements, a pressure transducer and thermocouple were installed just downstream of the flowmeter.

Initial calibrations did not give flow readings comparable to the respective compressor outputs. The flow profile just upstream of the flowmeter thus had to be investigated, as Annubar type flowmeters are sensitive to the upstream velocity profile.

Vertical and transverse air velocity profiles were taken to determine whether the flow was fully developed or not. (See Appendix B for graphs of velocity profiles). Pitot static tube measurements indicated that the profile was asymmetrical and would thus lead to inaccurate flow measurements.

This asymmetry was caused by the piping geometry as well as the various reductions and increases in pipe diameter upstream of the flowmeter.

The asymmetry was rectified by changing all the pipes to 6" pipes, as well as the installation of a flow straightener. The flow straightener consisted of ordinary drinking straws packed longitudinally into the pipe, and held in position by a fishing net.

Subsequent calibrations gave consistent outputs, comparable with the rated compressor outputs. It was also discovered that the minimum measurable flowrate was 9 kg/min.

The electrical outputs from the thermocouple, pressure transducer and Annubar were then all connected to the datalogger for automatic readings.

4.3.2 Solids mass flowrate

A set of three load cells were mounted in a triangular fashion underneath hopper 1. The load cell output was also connected to the datalogger. Modifications to the mounting system were required since the hopper was originally designed for 4 load cells. An extra bracket had to be installed to accommodate the 3rd load cell.

4.4 Data acquisition

All electrical outputs were connected to a Hewlett Packard data acquisition unit. There was no pre-written software available for this particular test rig. A program written in HP basic was developed to do the following:

- * Read the signals acquired by the datalogger at user determined intervals during the test. All readings were taken 3 times in quick succession and averaged out to be stored as one data point.
- * Store the data on floppy disk.
- * Retrieve the data for graph processing or hardcopying.
- * Plot any parameter against any other recorded parameter.
- * Average out the data for any particular test and print out a test result summary sheet.
- * All processed data i.e. solids mass flowrate, air mass flowrate as opposed to direct data i.e. pressure readings, was also calculated and stored. (See Appendix C)

All data were transferred to a Lotus 1-2-3 spreadsheet where software was developed to process the results.

5 DEVELOPMENT OF EXPERIMENTAL PROCEDURE

It was originally proposed that the carbides would be tested using short radiused bends. The bends were milled out at the point of maximum wear. Specimens could then be placed over the milled area and thus be exposed to the flow. In this way, the specimens could be tested under the closest conditions to an actual bend.

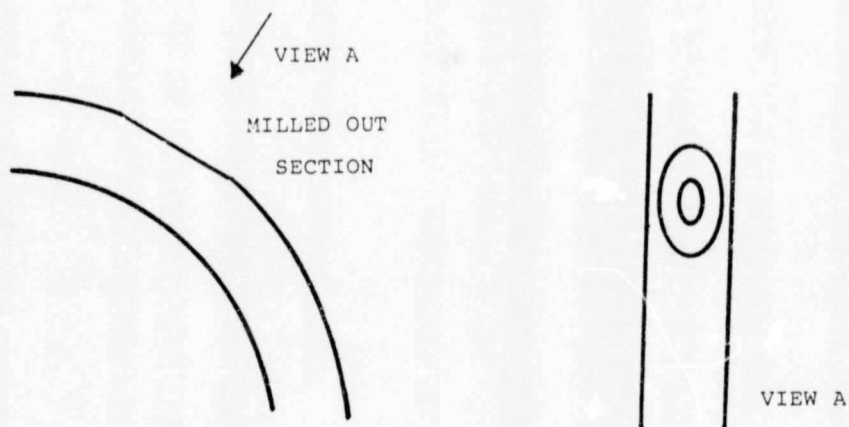


Figure 27. Radius bend with milled out section at $\pm 30^\circ$ to expose the point of maximum wear to the sample.

Tests were conducted with mild steel and WC-Co specimens using this testing geometry shown above in figure 27. It was found that the size of the hole in the pipe increased too rapidly and thus the bend wore out before any significant wear readings could be obtained. A WC-Co insert was designed and made to try to keep the wear hole a constant size, as well as prolonging the life of the pipe. To use this insert, a bigger hole was milled in the bend. The WC-Co insert, which had been shaped to the same internal radius as the bend, was then glued onto this hole and the specimens glued onto the insert.

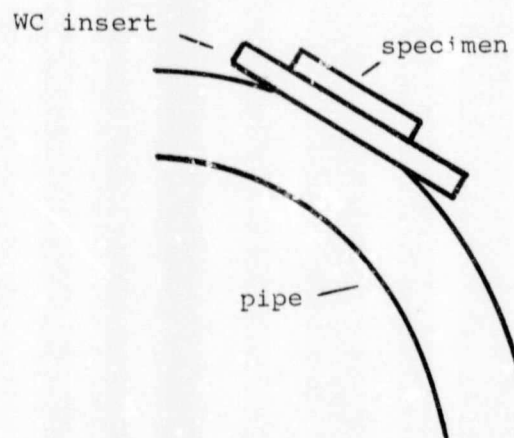


Figure 29. Schematic of WC-Co insert over the milled out section of the bend.

The WC-Co insert was successful in that it kept the wear hole a constant size, but it did not prevent the mild steel bend wearing out at the juncture between the WC-Co insert and the bend. For this reason the use of the WC-Co insert was discontinued.

The milled radius bend testing configuration was also discontinued for the following reasons:

- a) Exposed wear area could not be kept constant
- b) The cost of replacing the bends was prohibitive
- c) Only one specimen could be tested per bend

It was then decided that the best way of monitoring the testing conditions was to use a Tee-bend. A specimen holder was designed and made to fit into the bend (Figures 29, 30, Pg 63). The specimen holder could be set at various angles to test the influence of impact angle.

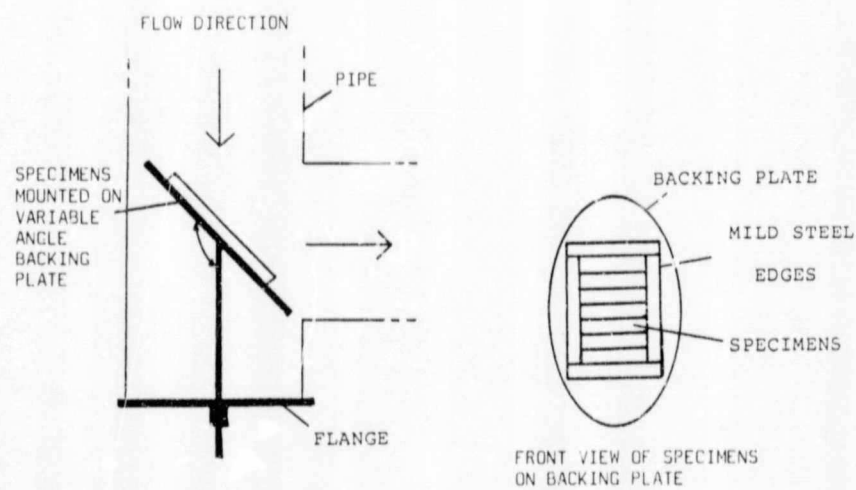


Figure 29. Schematic of specimen holder and the position of the specimens on the holder.



Figure 30. Photograph of specimen holder and its position in the Tee-Bend.

Author Freinkel D M (David M)

Name of thesis Experimental Investigation Into The Wear Resistance Of Tungsten Carbide-cobalt Liners In A Full Scale Pneumatic Conveying Rig. 1988

PUBLISHER:

University of the Witwatersrand, Johannesburg

©2013

LEGAL NOTICES:

Copyright Notice: All materials on the University of the Witwatersrand, Johannesburg Library website are protected by South African copyright law and may not be distributed, transmitted, displayed, or otherwise published in any format, without the prior written permission of the copyright owner.

Disclaimer and Terms of Use: Provided that you maintain all copyright and other notices contained therein, you may download material (one machine readable copy and one print copy per page) for your personal and/or educational non-commercial use only.

The University of the Witwatersrand, Johannesburg, is not responsible for any errors or omissions and excludes any and all liability for any errors in or omissions from the information on the Library website.