EXPERIMENTAL INVESTIGATION INTO THE WEAR RESISTANCE
OF TUNGSTEN CARBIDE-COBALT LINERS
IN A FULL SCALE PNEUMATIC CONVEYING RIG

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28 May 1985

RESEARCH PROJECT SUBMITTED FOR
MASTERS DEGREE IN ENGINEERING
DECLARATION

I, David Freinkel, declare that the work contained in this research project is my own. It is being submitted for the Degree of Master of Science in Engineering at the University of the Witwatersrand, Johannesburg. It has not been submitted before for any degree or examination at any other university.

David Freinkel

7/7/58
Date
The results from this research project have been published in a paper entitled "Pipe Bend Wear - Is Tungsten Carbide the Answer?", in the South African Mechanical Engineer, March 1988, Vol. 38 No. 3, pp 142-148. It is co-authored by Graham Wright o. the CSIR, and Professor Roy Marcus of Pretoria University.

A second paper entitled "Energy Loss Mechanisms in the Erosion of Cemented Tungsten Carbide" is being submitted for publication in the international journal "Wear", and is co-authored by Dr Sylvana Luyckx of the Schonland Research Centre at the University of the Witwatersrand. This paper is based on section 7.5, page 109; Effect of plastic deformation.
ABSTRACT

The purpose of the investigation was to compare the relative wear resistance of various grades of sintered tungsten carbide liners against a mild steel standard in a full scale pneumatic conveying testing rig.

Specimens ranging in cobalt content from 6% to 30% and in grain size from 0.56 to 2.98 micrometers, including a mild steel standard, were placed on a specially designed holder which fitted into a tee type 100 mm diameter bend. The specimens were tested under various operating conditions i.e. air velocity ranging from 28 m/s to 52 m/s, impact angles of 30° to 70°, mass flow rates of 35 kg/min to 83 kg/min and phase densities of 1.2 to 2.9, using a 4 mm nominal size crushed granite rock.

The experimental results show that the ultrafine grained, low cobalt (6%) tungsten carbide displays little sensitivity to varying velocities, impact angles, mass flow rates or phase densities, and consistently gave the best wear resistance under all testing conditions.

The coarse grained high cobalt (30%) tungsten carbide's wear resistance was found to be the most sensitive to an:
- increase in conveying air velocity
- decrease in phase density
- decrease in solids mass flow rate
- decrease in impact angle.

This material consistently showed the least wear resistance under all testing conditions and performed only slightly better than mild steel.

The effect of the carbide grain size was found to be small. However, the medium grained alloy displayed a higher erosion resistance than the fine grained alloy. This is due to the effect of plastic deformation, which determines the WC grain size that yields optimum erosion resistance, (if one excludes the ultrafine grained alloy which is expensive to produce).

The effect of cobalt content was such that the lower cobalt specimens (6% range) consistently performed better than the higher cobalt contents (10%, 15%, 30%) under all testing conditions; the wear resistance decreasing with increasing cobalt content.

Microstructurally it has been shown that there is a definite relationship between erosion resistance and the inverse of the magnetic coercivity of the tungsten carbide alloys.

Maximum erosion occurring below 90° has been explained in terms of a combination of three energy mechanisms i.e. removal of cobalt, plastic deformation of the target specimens and fracture of the erodant particles.
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* Mr D Strydom of Rectifier Controls for his advice on the control aspects of the test rig.
NOMENCLATURE

- P  Pressure in conveying pipeline (Kpa)
- L  Length of pipeline (meters)
- G  Solids mass flowrate (kg/min)
- V  Air velocity in pipeline (m/s)
- FF6  Ultrafine grained 6% (wt%) cobalt alloy
- F6  Fine grained 6% (wt%) cobalt alloy
- M6  Medium grained 6% (wt%) cobalt alloy
- C6  Course grained 6% (wt%) cobalt alloy
- C15  Course grained 15% (wt%) cobalt alloy
- C30  Course grained 30% (wt%) cobalt alloy
<table>
<thead>
<tr>
<th>FIGURE NO.</th>
<th>PAGE</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>State diagram for horizontal conveying.</td>
</tr>
<tr>
<td>2</td>
<td>Change in specimen weight as erosion takes place.</td>
</tr>
<tr>
<td>3</td>
<td>Three types of impact damage.</td>
</tr>
<tr>
<td>4</td>
<td>Variation of specific erosion with velocity</td>
</tr>
<tr>
<td>5</td>
<td>Variation of penetration rate with phase density.</td>
</tr>
<tr>
<td>6</td>
<td>Variation of erosion with phase density for 70 micron sand.</td>
</tr>
<tr>
<td>7</td>
<td>Variation of erosion with phase density for 230 micron sand.</td>
</tr>
<tr>
<td>8</td>
<td>Influence of impact angle on erosion</td>
</tr>
<tr>
<td>9</td>
<td>Variation of penetration rate with particle size.</td>
</tr>
<tr>
<td>10</td>
<td>Effect of particle hardness on erosion.</td>
</tr>
<tr>
<td>11</td>
<td>Effect of cobalt content in the mechanical properties of WC-Co.</td>
</tr>
<tr>
<td>12</td>
<td>A schematic representation of the WC-Co alloy illustrating the microstructural parameters.</td>
</tr>
<tr>
<td>13</td>
<td>Effect of hardness on the abrasion of metals, alloys and cemented carbides by quartz abrasives</td>
</tr>
<tr>
<td>14</td>
<td>The relative abrasive resistance and hardness of WC-Co alloys as a function of composition and grain size.</td>
</tr>
<tr>
<td>15</td>
<td>Variation of the loss in weight of the specimens of the abrading disk with $K_{IC}$.</td>
</tr>
<tr>
<td>FIGURE NO.</td>
<td>PAGE</td>
</tr>
<tr>
<td>-----------</td>
<td>------</td>
</tr>
<tr>
<td>16</td>
<td>44</td>
</tr>
<tr>
<td>17</td>
<td>46</td>
</tr>
<tr>
<td>18</td>
<td>47</td>
</tr>
<tr>
<td>19</td>
<td>48</td>
</tr>
<tr>
<td>20</td>
<td>49</td>
</tr>
<tr>
<td>21</td>
<td>52</td>
</tr>
<tr>
<td>22</td>
<td>53</td>
</tr>
<tr>
<td>23</td>
<td>53</td>
</tr>
<tr>
<td>24</td>
<td>54</td>
</tr>
<tr>
<td>25</td>
<td>55</td>
</tr>
<tr>
<td>26</td>
<td>57</td>
</tr>
<tr>
<td>27</td>
<td>61</td>
</tr>
<tr>
<td>28</td>
<td>62</td>
</tr>
<tr>
<td>29</td>
<td>63</td>
</tr>
<tr>
<td>30</td>
<td>63</td>
</tr>
<tr>
<td>31</td>
<td>66</td>
</tr>
<tr>
<td>32</td>
<td>67</td>
</tr>
</tbody>
</table>

Effect of cobalt content on erosion rate as a function of particle velocity.  
The effect of particle velocity on the erosion of a WC 6% Co alloy as a function of impingement angle.  
The effect of the angle of particle impingement on the erosion of a WC 9% Co alloy as a function of particle velocity.  
Erosion versus impingement angle.  
Schematic of the impact event size versus microstructural scales.  
Schematic of hopper feeding system.  
Photograph of hopper feeding and filter system.  
Photograph of vibratory feeder.  
Schematic of complete conveying rig.  
Photograph of pipeline system.  
Example of output of solids mass flowrate.  
Radius bend with milled out section.  
Schematic of WC-Co insert over the milled out section of the bend.  
Schematic of specimen holder and position of the specimens  
Photograph of the specimen holder and its position in the T-bend.  
Results of preliminary wear tests at 45° impact angle showing a vertical wear gradient across the pipe.  
Results of preliminary wear tests at 45° and 70° showing the horizontal wear profile across the pipe.
FIGURE NO.                    PAGE
33  Graphs showing the results of the impact angles tests at 51° and 70°.       69
34  Graphs showing the results of the repeatability tests using WC-Co specimens at 51° and 70°. 71
35  State diagram for wear rig showing the chosen test points.                4
36  Photograph of specimens mounted on the specimen holder.                  70
37  Erosion versus air velocity for all specimens tested.                    83
38  Results of the erosion versus phase density.                             85
39  Graph of erosion versus impact angle.                                    88
40  Graph of erosion versus cobalt content, showing the influence of velocity.90
41  Erosion versus %Co as a function of mass flowrate.                       92
42  Erosion versus %Co as a function of impact angle.                        93
43  Graph of erosion versus tungsten carbide grain size showing the influence of velocity. 95
44  Erosion versus grain size as a function of mass flowrate.                97
45  Erosion versus grain size as a function of impact angle.                 98
46  Graph of erosion versus tungsten carbide hardness showing the effect of velocity. 10
47  Erosion versus hardness as a function of mass flowrate.                  102
48  Erosion versus hardness as a function of impact angle.                   103
<table>
<thead>
<tr>
<th>FIGURE NO.</th>
<th>PAGE</th>
</tr>
</thead>
<tbody>
<tr>
<td>49</td>
<td>105</td>
</tr>
<tr>
<td>50</td>
<td>106</td>
</tr>
<tr>
<td>51</td>
<td>106</td>
</tr>
<tr>
<td>52</td>
<td>106</td>
</tr>
<tr>
<td>53</td>
<td>106</td>
</tr>
<tr>
<td>54</td>
<td>108</td>
</tr>
<tr>
<td>55</td>
<td>111</td>
</tr>
<tr>
<td>56</td>
<td>112</td>
</tr>
<tr>
<td>57</td>
<td>114</td>
</tr>
<tr>
<td>58</td>
<td>117</td>
</tr>
<tr>
<td>59</td>
<td>122</td>
</tr>
</tbody>
</table>

Graph of erosion versus the inverse of coercivity showing the influence of velocity.

SEM of ultrafine 6% Co alloy.

SEM of coarse 6% Co alloy.

SEM of coarse 15% Co alloy.

SEM of coarse 30% Co alloy.

SEM of the worn surface of a mild steel specimen.

Graph of erosion versus impact angle for the 6% cobalt range.

Effect of WC grain size on compressive stress-strain curves of a 6% cobalt alloy.

Schematic of erosion vs WC grain size

Schematic of the energy transformations involved in the erosion process.

Photograph showing the edge effects caused by unequal sample heights.
LIST OF TABLES

<table>
<thead>
<tr>
<th></th>
<th></th>
<th>PAGE</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Test matrix of tungsten carbide alloys.</td>
<td>77</td>
</tr>
<tr>
<td>2</td>
<td>Table of velocity coefficients for each material.</td>
<td>82</td>
</tr>
</tbody>
</table>
INDEX

DECLARATION i
PREFACE ii
ABSTRACT iii
ACKNOWLEDGEMENTS iv
NOMENCLATURE v
LIST OF FIGURES vi
LIST OF TABLES x

1 INTRODUCTION
1.1 INTRODUCTION 1
1.2 MOTIVATION FOR THE USE OF TUNGSTEN CARBIDE AS AN ALTERNATIVE PIPE BEND MATERIAL 4
1.3 PROJECT OBJECTIVES 5
1.3.1 TUNGSTEN CARBIDE PARAMETERS 5
1.3.2 PNEUMATIC CONVEYING PARAMETERS 5

2 REVIEW OF THE LITERATURE
2.1 INTRODUCTION 6
2.2 PNEUMATIC CONVEYING 6
2.2.1 INTRODUCTION 6
2.2.2 BASIC THEORY OF PNEUMATIC CONVEYING 7
PRIME MOVER 7
FEEDING/MIXING/ACCELERATION ZONE 7
CONVEYING ZONE 8
GAS/SOLIDS SEPARATION ZONE 8
2.2.3 MODES OF PNEUMATIC CONVEYING 9
DILUTE PHASE 9
DENSE PHASE 9
STATE DIAGRAM 11
WEAR IN PNEUMATIC CONVEYING 13
2.3 REVIEW OF EROSION OF PIPE BENDS 14
2.3.1 INTRODUCTION 14
2.3.2 THEORY OF EROSION 14
2.3.3 MECHANISMS OF EROSION 16
DUCTILE EROSION 16
BRITTLE EROSION 18
DUAL PHASE EROSION 18
2.3.4 CONVEYING PARAMETERS 19
AIR VELOCITY 19
SECONDARY FLOWS 20
EFFECT OF CONDITION OF CONVEYING PRODUCT ON VELOCITY 20
PHASE DENSITY 21
EFFECT OF CONDITION OF CONVEYED PRODUCT ON PHASE DENSITY 25
IMPACT ANGLE 27
PARTICLE SIZE 28
PARTICLE SHAPE 30
MOISTURE CONTENT 30
PARTICLE HARDNESS 30
BEND RADIUS 31
2.3.5 ERODED MATERIAL CHARACTERISTICS
SURFACE HARDNESS
TOUGHNESS

2.4 MECHANICAL PROPERTIES OF TUNGSTEN CARBIDE
2.4.1 INTRODUCTION
2.4.2 EFFECT OF COBALT CONTENT
2.4.3 MICROSTRUCTURAL FEATURES OF TUNGSTEN CARBIDE
MEAN FREE PATH
CONTIGUITY
CARBIDE GRAIN SIZE
2.4.4 EFFECTS OF MICROSTRUCTURAL PARAMETERS ON HARDNESS
COBALT CONTENT
MEAN FREE PATH
GRAIN SIZE
2.4.5 FRACTURE TOUGHNESS

2.5 EROSION OF TUNGSTEN CARBIDE COBALT ALLOYS
2.5.1 INTRODUCTION
2.5.2 EFFECT OF MATERIAL PARAMETERS
HARDNESS
FRACTURE TOUGHNESS
TRANSVERSE RUPTURE STRENGTH AND COMpressive STRENGTH
2.5.3 EFFECT OF PHYSICAL PARAMETERS
COBALT CONTENT
GRAIN SIZE, MEAN FREE PATH AND CONTIGUITY
2.5.4 EFFECT OF CONVEYING PARAMETERS
VELOCITY
ANGLE OF IMPINGEMENT
PARTICLE SIZE
PHASE DENSITY
2.5.5 MODES OF MATERIAL REMOVAL

3 DESCRIPTION OF WEAR RIG
3.1 HOPPER SYSTEM
3.2 PIPELINE
3.3 PRIME MOVER SYSTEM

4 DEVELOPMENT OF INSTRUMENTATION AND COMMISSIONING OF TEST RIG
4.1 CONTROL SYSTEM
4.2 BEND PRESSURE MONITORING
4.3 FLOWRATE MEASUREMENT SYSTEMS
4.3.1 AIR FLOWRATE
4.3.2 SOLIDS MASS FLOWRATE
4.4 DATA ACQUISITION

5 DEVELOPMENT OF EXPERIMENTAL PROCEDURE
5.1 EFFECT OF ORIENTATION OF SAMPLE ON WEAR
5.1.1 VERTICAL WEAR PROFILE
5.1.2 HORIZONTAL WEAR PROFILE
5.2 EFFECT OF IMPACT ANGLE
5.4 REPEATABILITY TESTS FOR TUNGSTEN CARBIDE
5.5 CONCLUSION
6 METHOD OF EXPERIMENTATION 73

6.1 EXPERIMENTAL PROCEDURE 73
6.1.1 PNEUMATIC CONVEYING TEST MATRIX 76
6.1.2 MATERIAL TEST MATRIX 77
6.2 TEST PROCEDURE 78
6.2.1 SAMPLE PREPARATION 78
6.2.2 RUNNING OF TEST 79

7 RESULTS AND DISCUSSION 81

7.1 PNEUMATIC CONVEYING PARAMETERS 81
7.1.1 INFLUENCE OF AIR VELOCITY 81
7.1.2 INFLUENCE OF SOLIDS MASS FLOW RATIO 84
7.1.3 INFLUENCE OF IMPACT ANGLE 86
7.2 TUNGSTEN CARBIDE PARAMETERS 89
7.2.1 INFLUENCE OF COBALT CONTENT 89
7.2.2 INFLUENCE OF TUNGSTEN CARBIDE GRAIN SIZE 94
7.2.3 INFLUENCE OF HARDNESS 99
7.3 DETERMINATION OF EROSION BY MAGNETIC COERCIVITY 104
7.4 SURFACE ANALYSIS USING SCANNING ELECTRON MICROSCOPY 106
7.5 EFFECT OF PLASTIC DEFORMATION 109

8 CONCLUSIONS 118

9 RECOMMENDATIONS FOR FURTHER RESEARCH 121
9.1 RIG DEVELOPMENTS 121
9.2 FURTHER RESEARCH 121
9.3 FIELD TESTS 121

10 REFERENCES 123

APPENDIX A - INSTRUMENTATION
APPENDIX B - CALIBRATION CURVES
APPENDIX C - ACTUAL RESULTS, SAMPLE OUTPUT AND SAMPLE CALCULATION
APPENDIX D - THREE DIMENSIONAL SURFACE ANALYSIS
APPENDIX E - MATERIAL CHARACTERISTICS
APPENDIX F - SCATTER GRAPH
APPENDIX G - SOFTWARE PROGRAMS
1 INTRODUCTION
1.1 Introduction

The transportation of powdered and granular materials over short distances using gas as a carrier fluid has become a popular method of bulk materials handling over the past few years. This is so because it is generally a clean, fast, flexible, easily automated and controlled distribution system that has low maintenance and manpower costs. The system versatility can be illustrated by the wide variety of solids from sub-micron powders to live chickens to rocks of up to 80 mm diameter that can be conveyed (1).

The drawbacks, however, are the following:
* High power consumption
* Incorrect design can result in particle degradation
* Limited conveying distances
* Wear and abrasion of equipment

The wear and abrasion of the equipment is probably the most costly disadvantage, as long delays due to downtime and costly replacement of equipment are incurred to keep the system running.

In straight pipe runs wear rarely presents a problem, barring misaligned joints, but wear can be severe and a limiting factor where sudden transition sections occur, i.e. branches, diverter valves and pipe bends.
Previous experience has shown for example that a 100 mm diameter, 5 mm wall thickness, short radius bend can be worn through completely in less than one and a half hours while conveying 4 mm crushed granite rock at an air velocity of 50 m/s, and mass flow rate of 50 kg/min. Research has been conducted (2,3,4,5) for the purpose of understanding the pneumatic conveying parameters and internal particle flow patterns that influence the wear rate at pipe bends. Such an understanding will allow the conveying parameters and bend geometry to be optimised or alternative bend material selected, hence reducing wear to a minimum.

The bulk of the work conducted by other researchers (6,7,8) in this particular field of erosion of pipe bends and the influencing factors thereof, has been conducted using bench top type laboratory test rigs using silicon carbide abrasives. These types of test rigs employ a sandblasting machine to erode a specimen using an open jet of air in an enclosed space. Due to differing boundary conditions, these results are in many instances inappropriate for understanding the wear in a pipe bend. The other type of test rig employed is a scaled down small diameter pneumatic conveying system. These results, due to the nature of pneumatic conveying where the pipe to particle size ratio is critical, cannot be used with total confidence to predict the wear in a full size system. The small scale laboratory based work has consequently not been of much assistance in reducing wear in industrial sized pipelines. Some experimental work has, however, been carried out in various parts of the world.
Mills et al. (2,3,4,5), using a recirculating pipeline incorporating 140 mm radius, 50 mm bore mild steel bends as well as perspex bends, have established that there are a number of conveying parameters that influence the wear of pipe bends, the most important of these being:

* Conveying air velocity
* Phase density or solids mass flow ratio
* Impact angle
* Conveying particle size, shape, relative hardness and state of degradation

A number of theories (6,7,8) for wear have been proposed, but the mechanism of the wear of pipe bends is complex as all the above parameters act synergistically. It is generally accepted that the conveying air velocity and hence the particle velocity is the single most important parameter to influence the rate of wear. The other conveying parameter that is easily controlled but has only recently been shown to influence the wear rate (3), is the phase density (ratio of the solids/air mass flow rate). It has been found that, contrary to what one would expect, the wear rate decreases with an increase in phase density; the explanation being that the high concentration of particles in the pipe causes shielding of the exposed wear surface.

In general, the pneumatic conveying parameters are not easily changed. Hence one is forced to look at alternative materials or bend design to reduce pipe bend wear. It has been found for example (1) that in some applications tee bends display reduced amounts of wear, while long radius bends tend to develop primary, secondary and sometimes tertiary wear areas.
There is limited information pertaining to the performance of alternative materials for pipe bends, the bulk of research in this area having been done on mild steel. However, there is a vast range of materials from which to choose - rubbers, ceramics, polyurethanes, hard metals etc, and each material would have to be evaluated quantitatively.

1.2 Motivation for the use of tungsten carbide as an alternative pipe bend material

Tungsten carbide is used extensively in materials shaping, mining and wear resistant components - its hard particle/tough binder, dual phase tungsten carbide/cobalt combination provides exceptional wear resistance.

Pipe bends in pneumatic conveying systems are highly critical wear points. The "wear factor" is often the deciding parameter that determines what kind of bend geometry and material is to be used for a particular application, especially where highly abrasive materials are to be conveyed. The problem is to decide which type of bend and choice of material will be the most cost effective: ie does one choose a cheap bend and repair it frequently, or use an expensive material and incur less downtime?

Based on the above argument, an in-depth investigation into the wear performance of various tungsten carbide grades in pipe bends was conducted using a full scale pneumatic conveying rig so that realistic, accurately controlled data could be generated to establish initially whether tungsten carbide is suitable for this particular application or not.
1.3 Project Objectives

The objectives of this research project were to determine the wear performance characteristics of cemented tungsten carbide liners in pneumatic conveying systems as a function of the following parameters:

1.3.1 Tungsten Carbide parameters
   - Percent cobalt content
   - Grain size

1.3.2 Pneumatic conveying parameters
   - Conveying air velocity
   - Solids mass flow rate
   - Phase density
   - Impact angle of the particles on the wear surface

It was originally proposed that the particle size of the erodant (4 mm quartzite rock) would also be considered, but it was found to be impossible to control this parameter as a result of particle degradation.