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

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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.

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7/7/88

Date

PREFACE

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 of 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^{o} to 70^{o}, 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^{o} 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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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

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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 exampl 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 50kg/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 air to 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.