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Generation of transfer film and its effects on wear mechanisms in alumina conveying pipeline of mild steel

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ABSTRACT

Pipeline wear is a very complex problem and at present there is limited understanding of the wear mechanisms responsible for the reduction of wall thickness in severe wear regions of alumina conveying pipelines. The ability to determine the wear mechanisms in these areas holds the key in determining the service life of pneumatic conveying pipelines in these industries. In a previous paper it was revealed that delamination and subsequent cracking and spalling of a thin layer plays a major role in material removal in the severe wear regions in the pipeline. The thin surface layer is believed to be the transfer film of alumina generated in the internal pipe surface. In this paper, the transfer film developed in these areas of the pipeline have been analysed to determine its mechanical properties and to correlate the properties with the wear mechanisms observed earlier.

In this work, the transfer film formed on mild steel pipes during pneumatic conveying is investigated by using a UMIS nanoindenter. The benefit of using the nanoindenter lies in the very small force that can be applied so that only the properties of the transfer film are measured. The mechanical properties of the film such as the hardness and Young's modulus at different loads are measured. Attempts are also made to measure the fracture behaviour of the film.

The elemental analysis of the surface as well as the through depth was conducted using the SEM microanalytical technique EDS (energy dispersive X-ray spectroscopy) and XPS (X-ray photoelectron spectroscopy). The study found that the top layer of the surface is primarily aluminium with hardness value similar to that of sintered alumina.

1. Introduction

Many products in the manufacturing, pharmaceutical and fertilizer industries, to name a few, use feed-stocks in the form of powders. These powders are often agglomerates of even finer particles. Depending on the strength of these agglomerates, powder particles tend to break-up as they are transported. This is a major concern in bulk materials handing and subsequent processing operations on the powder material. The fine fractions can be made up of extremely small particles, fragments of the original. These fines tend to foul handling equipment by forming transfer films on the surface which alters the characteristics of the pipeline surface.

Pneumatic conveying is frequently employed in the alumina refining industry [1]. Due to the abrasive nature of the alumina particles, transfer films often form on the conveying pipes. Frequently influencing the degree of wear is the presence of a thin film on the internal surface of the piping through which the alumina is pneumatically conveyed. The film is formed by the adhesion of fine particles to the pipe surface in certain conveying conditions. Initially it acts as a protective barrier and reduces the extent of wear. However, with removal of the film some of the steel substrate is also lost, thereby increasing the degree of wear.

In this paper, the mechanical properties such as Young's modulus and hardness of the transfer film at different depths of indentations were measured using a UMIS 2000 nanoindenter. The fracture behaviour of the film was also examined using the continuous loading mode of the nanoindenter. Mechanical properties of the film are then correlated with the wear characteristics of the surfaces in the critical wear areas of the pipeline.

2. Background

Wear is surface damage that generally involves progressive material loss due to relative motion between the surface and the contacting substance or substances. The ability to determine the wear mechanisms call for a systematic study of the wear surfaces and the materials flow characteristics in the critical wear areas of the pipeline. Although there has been a significant development in

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the understanding of wear in a number of applications, it is apparent that underlying mechanisms of wear in pneumatic conveying applications has been ignored. Rather than looking at the fundamentals of the wear mechanisms, many researchers [1–3], for years looked into the problems as an aggregate loss of material in different areas of the pipeline. In many cases, it seemed that the industry has accepted to live with such a massive problem.

Pneumatic conveying is frequently used in the alumina refining industries to transport both primary and secondary alumina among many other bulk materials handling industries. Due to the abrasive nature of the alumina particles, wear is a serious problem in pneumatic conveying pipelines of alumina. Other than the production loss, the failure of the pipeline can cause big environmental hazard as a tiny hole in the pipeline can leak a large amount of fine particles into the atmosphere.

Abrasive and erosive wear mechanisms are extensively discussed in the literature and to some extent understood with reasonable accuracy [4,5]. In many cases, due to the interactions between the abrasives and the surfaces, the surface characteristics are altered that changes the wear mechanism from the parent materials. Work hardening [6] due to cutting and deformation of the surfaces, generation of transfer film [7] on the counter surfaces due to the recirculation of the abrasives are less understood processes in the field of mechanics of wear.

In general if there is relative motion between two surfaces, a preferential layer of material can be formed on the counter surface through different thermophysical processes. It was observed that transfer layer was formed on the ignimbrite abrasive while recirculating abrasive in the linear wear tester [8]. Transfer films formed by entrainment of ultra fine particles of abrasives into the surface and subsequent attachment of particles through sintering or other mechanical processes. The thermophysical properties of these transfer films are often completely different than those of original surfaces.

2.1. Wear in alumina conveying pipelines

To understand the severity of wear in the industries, Fig. 1 shows wear samples from an industrial pneumatic conveying pipeline used to transport primary alumina [9]. Fig. 1a shows the section of a bend and Fig. 1b shows the straight section of the pipeline. Fig. 1a shows a typical example of the bend protected by the particles accumulated in the bend. On the other hand, Fig. 1b showed the severe wear in the section after the bend. Observation of these sections revealed that there was no rust in certain areas of the wear sections even though they have been exposed to the atmosphere for a long period of time (more than 1 year). It was this observation that suggested that some type of protective coating (i.e. transfer film) has been formed in the conveying process which was protecting the mild steel surface from oxidisation.

The wear surfaces from the industrial pipeline have been studied extensively [9] to determine the dominant wear mechanisms in fluidised dense phase pneumatic conveying of alumina. One of the unique characteristics of the wear surfaces observed was the surface cracking and generation of crack network on the wear surfaces which clearly showed brittle nature of the surface layer that was being removed. These features are seen primarily along the wear grooves in the severe wear areas as seen in the following Fig. 2a. With careful observation of the surface, it was seen that the cracks are generated preferentially surrounding the rippled structures on the surface that are believed to be created during initial process of material removal through cutting and deformation.

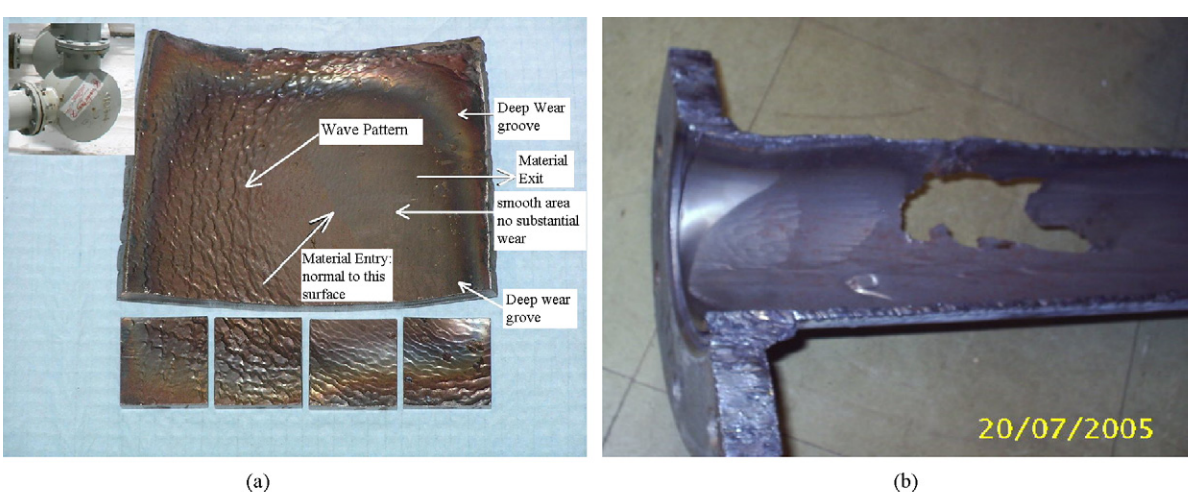
The Fig. 2b shows how the process of removal of the delaminated and fractured fragments starts. In this figure, a small fragment of the surface layer has fallen off while the surrounding area is still covered by the hard layer. With the removal of one segment of the surface, the surrounding segments are now less supported and can be removed relatively easily due to the impact of bulk materials. As the material is removed in large fragments, the rate of material removal at this stage is extremely high compared to cutting and deformation mechanisms [9]. Once the hardened layer is removed from the surface, a new undeformed ductile surface is revealed. The cutting and deformation wear which contribute to surface hardening become the effective wear mechanisms until the surface is hardened and the transfer film is formed and the cycle continues. A detailed account of the cyclic process of material removal has been presented in [10].

2.2. Nanoindentation

Nanoindentation has been used successfully to obtain the mechanical properties of various materials in the last decade. Pioneering work in this area has been done by Oliver and Phaar [11]. The hardness H of a material is defined as the ratio of contact force P and contact area A, which is expressed as:

$$H = P/A(h_c) \tag{1}$$

where the contact area A is a function of the contact depth h_c. The contact area as a function of displacement is determined from the tip geometry function $A(h_c)$ obtained from the calibration of inden-



(a) (b)

Fig. 1. Critical wear areas of an industrial pipeline and bend (a) bend section (b) straight pipe section after the bend.