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Final Project Report

Title: IDENTIFY METHODS TO REDUCE THE RISK OF
EXPLOSIONS AND FIRES CAUSED BY FRICTIONAL
IGNITION HAZARDS

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EXECUTIVE SUMMARY

This project was designed to have three primary outputs

- 1) A literature review of the extensive research conducted worldwide into the phenomenon of frictional ignition.
- 2) A review of whether machines currently used in South Africa comply with known principles for reducing frictional ignition risks.
- 3) Recommendations for improving the situation.

The literature search identified 155 papers, articles, reports and books directly related to this topic. Of these 100 have been obtained and are available to interested parties, while the remainder were consulted as summaries, precisés or on microfiche. While the literature on metal to metal and rock on rock ignitions needed to be reviewed, several excellent reviews of frictional ignition by cutting tools had already been undertaken. From these the known and accepted facts could be readily extracted.

Contact has been established with five research centres and a visit was made to the Health and Safety Executive (U.K.) laboratory at Buxton. Machine manufacturers have supplied information, as has the Department of Mineral and Energy Affairs and the South African coal mining industry.

Conclusions have been drawn from the literature reviewed and personal communications and recommendations formulated. From these the major points to emerge are that

- 1) techniques exist for evaluation of the frictional ignition risk at each site where a machine is deployed
- 2) for a variety of reasons continuous miners have not yet been adapted to incorporate the known methods of reducing the frictional ignition risk
- 3) the development of a wet head continuous miner, equipped with appropriately located sprays, is the best long term solution to this problem
- 4) in the interim and as a second line of defence, machine mounted active suppression systems should be considered for machines deployed at high risk sites.

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INTRODUCTION

An explosion starting as a gas ignition is probably the most feared hazard of coal mining. Such an ignition depends upon two random and independent contributory factors being present simultaneously - the incendive source and the explosive gas mixture. The probability of an ignition is equal to the product of the probabilities of the occurrence of the individual factors and this simple concept illustrates the fact that contributory risks combine in an associative manner and that the diminution of a single one makes an immediate impact on the total risk. No incendive source means no risk, even in the presence of gas.

It is important, therefore, to study the changing pattern of ignition sources in our coal mining industry, in order to see where improvements in safety measures have reduced the risk and where new problems have arisen as a result of deployment of new technology or changes in mining methods. Data for South African incidents for the past three decades has been analysed and, in Table 1, is compared with that for the first three years of the 1990's (Phillips¹⁰¹).

TABLE 1

The Changing Pattern of Ignition Sources

IGNITION SOURCES	PERIOD							
	1960s		1970s		1980s		1990 to 1992	
	I	%	I	%	I	%	I	%
CM Picks	0	0	1	5,5	14	29,5	6	25,5
CC Picks	1	4,5	3	17	11	22,5	0	0
Shearer Picks	0	0	0	0	1	2	0	0
Stone on Stone	0	0	0	0	4	8	1	4
Blasting	14	64	6	33,50	5	10	1	4
Spon Comb	0	0	0	5,5	0	0	2	8
Heated Surface	1	4,5	1	5,5	1	2	0	0
Naked Flame	2	9	1		0	0	0	0
Electricity	2	9	2	11	5	10	0	0
Lightning	2	9	4	22	3	6	0	0
UNKNOWN	0	0	0	0	5	10	14	58,5
TOTAL	22	100	18	100	49	100	24	100

I = number of incidents of ignitions/explosions

Two very obvious changes are the steady increase in frictional ignitions following the introduction of continuous miners (CM) in the early 1970's and an equally noticeable decrease in the percentage of incidents caused by blasting. Electricity, lightning, naked flames, etc. have all remained small and almost constant components of the total scene throughout the period 1960 to date.

A more realistic view of the current situation can be obtained from a detailed analysis of the past decade, with the sources of ignition being divided into three major categories, namely frictional, flame and electrical ignitions. Frictional ignitions include ignitions due to the cutting picks of continuous miners or road headers contacting stone, cutting picks of coal cutters, cutting picks of shearers and ignitions due to stone on stone or metal on metal friction. Flame ignitions include those due to blasting, spontaneous combustion or heated surfaces. Electric ignitions include ignitions due to electric sparks and lightning forming stray currents. Table 2 provides a list of the sources of ignition and the frequency at which they were involved during the past decade.

TABLE 2
Sources of Ignition In South African Collieries
For The Period 1984 - 1993

SOURCE OF IGNITION	IGNITIONS	EXPLOSIONS	TOTAL	% TOTAL
FRictionAL:				
CM Picks	8	3	11	21
CC Picks	2	0	2	4
Shearer Picks	1	0	1	2
Stone on Stone	3	0	3	5,5
FLAME/HEATED SURFACE:				
Blasting	0	2	2	4
Spontaneous Combustion	0	1	1	2
Heated Surfaces	1	0	1	2
ELECTRIC:				
Electric Sparks	1	2	3	5,5
Lightning Stray Currents	0	1	1	2
UNKNOWN	26	2	28	52

Friction obviously plays a dominant role as an ignition source, being the cause of 32,5% of all incidents. Since many of the ignitions and explosions where the cause was never determined may have also been due to friction, it is perhaps important to comment that of those incidents for which the cause was determined, frictional ignitions accounted for 68%. On the other hand blasting and electric sparks form only 8% and 12% respectively of the known sources of ignition.

The problem of frictional ignitions of gas is neither new nor unique to South Africa. As early as July 1675 a Mr Jessop of Broomhall, Yorkshire communicated with the Royal Society on the problem of frictional ignitions, "I never heard of damps that kindled of themselves, although I have been told that in some places they have been kindled by the motion of the sled in which they draw their coals." Furthermore, Mallard⁸⁵ reported in 1890 that firedamp could easily be ignited by the sparks from steel picks striking rock.

In countries with a considerable history of mechanised mining, there is a wealth of data on the extent of the frictional ignition problem. Browning¹⁷ has produced evidence of the growing trend of such incidents in the United Kingdom, despite a decline in the size of the industry.

TABLE 3
Ignitions in the U.K. 1951-1990

DIFFERENT IGNITION SOURCES						Frict %	Frict /100 Mt
Years	Shot-firing	Elec-trical	Cutting frict.	Other	Total		
1951-54	10	8	8	29	55	14.5	0.9
1955-58	15	4	13	49	81	16.1	1.6
1959-62	25	12	35	23	95	36.8	4.6
1963-66	25	9	51	10	95	53.7	7.0
1967-70	14	9	71	6	100	71.0	11.7
1971-74	11	5	52	1	69	75.4	11.3
1975-78	6	1	60	6	73	82.2	13.7
1979-82	3	4	57	4	68	83.8	13.1
1983-86		3	33	7	43	76.7	10.3
1987-90		1	34	3	38	89.5	11.4
Totals	109	56	414	138	717		

Hardman⁵⁹, commenting on the United Kingdom data, has concluded that "the rise in the number of frictional ignitions from the mid-50's to the mid-60's coincided with the increasing use of shearers. Although the number of frictional ignitions caused by cutting decreased since the late-1960's, the occurrence per 100 million tons mined remained virtually unchanged from 1967 to 1990."

Watson¹⁵² has reported that in the United States an average of 48 frictional ignitions occurred each year throughout the 1970's and of these 85% were caused by continuous miners.

The situation in Australia has been reviewed by the Department of Mineral Resources of New South Wales⁴⁷, where the Inspectorate's Reportable Occurrences statistics reveal that for the period 1 July 1987 to 31 December 1993 a total of 23 ignitions of methane were investigated. The location and type of incident can be inferred from the following table:-

TABLE 4
Reportable Ignitions of Methane Gas In NSW
Underground Coal Mines 1/7/87 to 31/12/93

TYPE OF INCIDENT	NUMBER
Continuous Miner Drum Picks	12
Continuous Miner Shovel	1
Continuous Miner Cable	1
Longwall Shearer Drum Picks	4
Rock Fall In Goaf	1
Cutting And Welding Operations	1
Roof Drilling/Bolting Operations	2
Filling Abandoned Shaft	1
Total	23

This data for NSW shows that all types of frictional ignition account for 20 of the 23 ignitions and that friction generated during the cutting action of machines operating at the face dominate the statistics with 16 out of 23 ignitions or 70% of incidents. During the time covered by this survey, 124,1 Mt of coal was mined in NSW by longwalls and 162,4 Mt by continuous miners. This gives a frictional ignition rate of 3,22/100 Mt for longwalls, 7,29/100 Mt for continuous miners and an overall rate of 5,58/100 Mt.

It can be concluded from the brief survey of coal mining in four countries that mechanised

methods of underground coal mining carry an inherent risk that machine picks will generate incendive sparking. Despite nearly a century of research, incidents of this nature occur regularly worldwide. In South Africa, where coal seams are significantly harder than average, cutting machines need to be powerful and relatively high drum rotation speeds are required in order to achieve acceptable production levels. In the presence of sandstone roof, floor or inclusions in the seam the likelihood of frictional ignitions must be high and so a study to identify the most appropriate preventative measures is warranted.

RESEARCH INTO FRICTIONAL IGNITIONS

Introduction

Although the phenomenon of frictional ignition was known and documented from the 17th century onwards, the first detailed accounts of experimental work undertaken in order to understand the mechanisms involved were reported by Mallard⁸⁵ in 1890. Sir Humphrey Davy⁴³ (of flame-safety lamp fame) had conducted research into the inflammability of different gases in 1815 but, following a colliery explosion at Verpilleaux in 1889, the French fire-damp Commission encouraged research into "lighting gas by sparks produced by striking with a pick on fragments of hard stone and nodules of ironstone."

By the 1920's serious, scientific study was being undertaken in several countries but notably in the United Kingdom through the Safety in Mines Research Board and in Germany. From the early days of this research it was recognised that there were three main types of frictional ignition:

- Pick on rock, as caused by a cutting tool during mining.
- Rock on rock, as occurs in roof falls.
- Metal on metal, as in mechanical equipment.

Although all three types of incident can produce sparking or heat of sufficient intensity to ignite methane, initiate a methane explosion or even, under the correct circumstances, lead to a devastating coal dust explosion, the analysis of South African explosions (Phillips¹⁰¹) clearly indicates the relative significance of each.

Frictional ignition by cutter picks is the area of most concern, since up to 70% of all ignitions are likely to be initiated by this means. Falls of ground, involving rock striking rock and sliding under pressure is a phenomenon thought to be the cause of ignitions in goaf areas that cannot be explained in any other way. Certainly recent research in Australia (Gray⁵⁵ and Ward¹⁵¹) has shown conclusively that a single rock on rock impact can cause an ignition of methane in air at sliding velocities such as might be encountered in a roof fall. Since this occurs under circumstances over which mines have the least control, this is again an on-going

cause for concern. Finally, metal on metal ignitions have been seen less frequently since the work on light alloys restricted their use. Frictional heatings such as in the rollers of belt conveyors can lead to devastating fires but are rarely involved in methane ignitions since they are in areas of the mine normally well ventilated. Metal on metal frictional ignitions do still occur, however, and recent occurrences, in New South Wales where a roofbolting rig boring a hole through a roof strap ignited gas and in the United Kingdom where drilling during roadway repairs ignited gas, indicate that there is always a possibility for this type of incident.

In reviewing the literature and preparing the bibliography for this report, the main emphasis has been on rock cutting ignitions, then on rock-on-rock ignitions, with only passing reference to the problem of metal-on-metal ignition.

Literature Search

As a major part of this project a literature search was undertaken which identified 155 relevant papers, research reports and articles. Of these 100 have been obtained for future reference, while the remainder were consulted either as summaries, precisés or on microfiche. The staff of the Kloppersbos Research Facility of the CSIR must be thanked for their help, as fifty four references were retrieved from their data bank. Mr David Brearley of the Safety and Health Executive at Buxton also assisted greatly by locating and supplying copies of many of the early research reports, dating back to 1925.

While conducting the literature search it became obvious that several highly competent reviews of previous work have been conducted over the years.

In the 1950's the programme of basic research in the United Kingdom, which started in the early 1920's, reached completion. It was reviewed by Wynn¹⁵⁴ in 1952 and Titman¹⁴⁶ in 1955. In the same year Hartmann⁶⁰, working at the United States Bureau of Mines, produced an excellent review of previous research from both Germany and the United Kingdom, together with a history of gas ignitions by friction in the coal mines of the United Kingdom, Germany and the United States.

In the 1960's the use of coal mining machines increased dramatically, with a concomitant increase in the number of frictional ignitions. It was realised that the early research which had examined the mechanisms of frictional ignition had produced little of value in helping to prevent their occurrence and the focus of the research programmes changed. Since the information necessary to design machines, picks and remedial measures such as water spray systems could only be gained by tests on a practical scale, large laboratory experimental rigs were developed and used throughout the 1970's. Results of this research were incorporated into the next two major reviews, both of which were undertaken in South Africa. Trueman¹⁵⁰ in 1985 and McVey⁹⁵ in 1987 looked at the problem for a very specific reason - with the growing use of machines in South African collieries, there was an obvious need for mining engineers in this country to understand the causes of ignitions and methods for reducing the frequency of their occurrence.

The major research effort at Buxton was completed in the late 1980's and Powell, who had made a very significant contribution to the programme completed this work by publishing two definitive review papers, covering ignitions by machine picks^{108, 110} and ignitions during roof falls¹¹¹. Finally, Hardman⁵⁹ reviewed the literature as part of a CSIR discussion document on the potential of machine mounted ignition suppression systems.

Literature Review

Since the literature on frictional ignitions by picks has been so exhaustively reviewed, nothing further could be gained in this regard by duplicating the effort of others. In particular, anyone wishing to become familiar with this subject is advised to study the review papers of Powell, listed in the Bibliography section as items 108 and 110. On the other hand, ignitions during roof falls and from metal to metal collisions have not been dealt with so thoroughly.

In structuring this report, it is proposed that the literature concerning rockfall ignitions be reviewed first, followed by a short examination of metal on metal ignitions. The more important problem of ignitions by machine picks can then be addressed by looking at the list of known facts and discussing preventative measures based on them.

Ignitions During Roof Falls

Ignitions of methane-air mixtures by roof falls are not common and because of their location are usually difficult to investigate. However, there are many reports of sparking and bright flashes being observed during goaf collapses, as well as explosions where the only reasonable explanation is an ignition caused by a fall of roof. In recent years, since the introduction of roof bolting for strata control, some of these incidents have also involved the breaking of steel roof bolts. There are, therefore, four possible sources of ignition:

- 1) A spark or hot surface produced by the breaking of a bolt.
- 2) Impact of steel on steel i.e. between the broken parts of the bolt or between bolts and roof plates.
- 3) Impact between rock and rock.
- 4) Impact between bolts and the surrounding strata.

The ignition of gas-air mixtures has been investigated by Titman^{146, 147}, who fired steel balls at targets of various materials to produce fracturing. While hydrogen-air mixtures could be ignited, pentane-air and methane-air mixtures could not be ignited. Other research involving fractures in ocean-going oil tankers concluded "It is generally accepted that the energy directly associated with the failure of the ship's steel would be too small to cause the fracture surface to increase in temperature sufficiently to cause ignition." It is considered by Powell¹¹¹ that "it is very unlikely that any heating or sparks caused by fracture of a steel roof bolt would be sufficient to ignite methane-air mixtures, because of the high temperature necessary." This temperature is highly dependant on the source of heat and its dwell time but is probably a minimum of 640°C.

The continuous rubbing of steel on steel can, with sufficient power available, raise the temperature to at least the melting point of the material. Thus there is no real difficulty in reaching temperatures high enough to ignite methane. This is the situation described earlier of a drill steel rubbing on a roof strap and leading to an ignition.

On the other hand direct impact of steel on steel results only in a small temperature rise due to deformation of the material and any hot surface produced does not extend to any depth into the material, resulting in a very rapid cooling. Powell¹¹¹ has stated that "Impact of steel on

steel during a roof collapse is also very unlikely to cause ignition. The evidence points to the need for exceptionally hard (VPN > 700) steel to be involved for ignition to occur in drop-weight experiments."

Research¹¹³ has shown that rocks with a high quartz content are capable of producing high temperatures during continuous rubbing. Gray⁵⁵ has also shown that it is possible for a single rock on rock impact to cause an ignition of methane in air at velocities that might be encountered in a roof fall. Ward¹⁵¹, also working in Australia has recorded ignitions using a video camera and this has shown conclusively that the source of ignition was the hot spot developed at the point of contact and not the associated sparking.

In the United Kingdom rocks in the vicinity of all coal seams are sampled regularly and examined for quartz content. It is considered that rocks containing less than 20% quartz are probably not a hazard; rocks containing more than 40% quartz are a definite hazard; those in between may or may not be a hazard, depending on their strength. Ward et al¹⁵¹, on the other hand, believe that, for Australian rocks at least, assessment of frictional ignition potential from mineralogical data, requires more than a simple determination of the quartz content. They have proposed a five-point scale for categorizing the frictional ignition potential of rocks rubbing on rock. Nagy and Kawenski⁹⁷, as long ago as 1960, showed the ease with which sandstone on sandstone could ignite methane in air, while fracturing of a roofbolt or pulling a roofbolt through a washer and roof plate failed to ignite the gas. Powell¹¹¹ in summarizing the literature states "Impact of rock on rock, although never demonstrated to ignite methane-air in drop-weight experiments, must be considered a possible cause of ignitions. Although during an impact the sliding distance is in the order of millimetres, it is considered that large slabs of rock could slide sufficiently far, i.e. 0,2 m for ignition to be possible.

The last form of contact during roof falls involves steel, i.e. roofbolts or other forms of support or equipment and rock. This has been known for centuries to cause sparks and that these are incendive. A great deal of research involving cutter-machine picks, rubbing experiments, drilling of rock and high-speed impact of metal on rock has shown time and again that the contact of steel on rock can cause ignitions. Perhaps the most telling argument is that a miner's hand pick can cause ignitions of methane-air when it strikes various sandstones (Burgess and Wheeler²⁴, 1930). If the energy generated by a man swinging a pick

is sufficient, then blocks of sandstone falling from the roof onto a previously displaced roofbolt will most certainly be able to ignite methane.

The most likely cause of an ignition caused by a roof fall must, therefore, be regarded as impact between steel and rock.

Metal To Metal Ignitions

Metal to metal ignitions can be caused either by rubbing friction, such as exists between a rotating steel wheel and a stationary piece of metal or by the impact of two metal objects.

Research by Burgess and Wheeler²³, Schultze-Rhonhof¹³⁵, Schultze-Rhonhof and Weischel¹³⁶, Thomas¹⁴¹, Bailey⁵, Bowden¹³, Desy et al⁴⁶, Kingman⁷⁰ and others has shown that in metal to metal contact the properties of the more readily oxidizable metal normally determine the degree of ignition hazard. The hardness, melting point, ignition temperature, specific heat, heat conductivity and brittleness of the metals all play a role, in that they determine the size, duration, temperature and heat capacity of the incensive sparks.

Rubbing friction between two iron or steel surfaces will cause ignition of methane-air mixtures only if the friction is great enough to raise the temperature of the steel surfaces to a white heat. Where friction between steel surfaces produces a cloud of sparks, these will not ignite methane unless concentrated by hitting some object (Wynn¹⁵⁴). However, in coal mining it must be remembered that the friction in machine bearings and between steel surfaces is dangerous for a quite different reason. Coal dust begins to smoulder if raised to a temperature of about 180°C and this can lead to a fire.

The problem is, however, different if metals other than steels are used. In the 1940's and 1950's there were a number of ignitions in European coal mines that were attributed to the use of aluminium or magnesium alloys (Bailey⁵). In some cases, it was noted that the rusted steel surfaces had first become smeared with aluminium before being subjected to rubbing friction under high-bearing pressure. In other cases, the aluminium part was believed to have been impacted by a blow from a hammer or a pick. These observations led to experimental tests being conducted by a number of investigators. Schultze-Rhonhof¹³⁵, Titman¹⁴⁶,

Brenner¹⁵, Balek⁶, Nagy⁹⁷ and Rae¹¹⁸ all investigated the problem of aluminium or light-alloys being rubbed or struck against steel. Probably the most pertinent research followed an incident in a British coal mine in which a 16 kg drilling machine with a magnesium-alloy casing was dropped on a rusty steel girder. Margerson⁸⁶ conducted a number of drop-weight experiments where alloy weights were dropped onto inclined rusty steel plates. Under a variety of conditions, vivid sparking and ignition frequently occurred.

In summary, the results of this considerable body of research indicate

- (a) that the test conditions have a strong influence on the incendivity of a material combination. More flammable atmospheres, higher velocity or energy of impact and higher bearing pressure during frictional contact all can increase the incendivity of a given pair of materials and may cause ignitions where none were observed under less severe conditions
- (b) aluminium alloys very easily cause frictional ignitions when they contact rusty steel. The argument as to whether this is due to a thermite reaction (Titman¹⁴⁵), the evolution of hydrogen during the rusting process being accelerated in the presence of finely divided aluminium (Brenner¹⁵) or the formation of local electrolytic cells (Schultze-Rhonhof¹³⁵) is still open
- (c) harder aluminium alloys are generally more incendive than softer alloys and the additional of several percent of silicon to the alloy exacerbates the situation. Similar tests have shown that steels with high silicon contents, although requiring a great deal more energy input than the aluminium tests, also caused ignitions
- (d) even aluminium paint on rusted steel, when struck by a hard object, can produce incendive sparking. Grice⁵⁶, Kingman⁷⁰ and Thomas¹⁴⁰ all verified this, although in most cases the painted surface had to be heated to at least 200°C before sparking occurred.

The research findings outlined above lead to several conclusions that can improve coal mine safety. These are:-

- (1) rubbing friction of steel on steel is unlikely to lead to frictional ignitions of methane in air but should be avoided because of the risk of igniting coal dust and causing a fire
- (2) the use of high-silicon steel should be avoided and rust on the surfaces of steel roof supports and other structures prevented. The latter can be accomplished by using galvanised steel or by applying zinc metal sprays or zinc chromate coating
- (3) aluminium paints should not be used on steel surfaces in coal mines
- (4) the use of light alloys and particularly magnesium-based alloys should be limited or prohibited entirely. If their limited use is permitted care should be exercised to avoid friction and impact of all light metal alloys with steel and hard rocks.

Known Facts Concerning Cutter Pick Ignitions

As discussed in the literature search and literature review sections of this report, a vast amount of research has been conducted into cutter pick ignitions. Most of this has been thoroughly reviewed and from this a number of almost universally accepted facts have emerged. Rather than conduct yet another review these "known facts" are now discussed.

- (1) Ignition Mechanisms. Early researchers believed that sparks produced by picks could ignite gas. However, Blichensderfer et al^{9,10} and Burgess and Wheeler²³ have shown that sparks do not usually possess an adequate combination of life time, temperature and surface area to ignite methane, which has a high ignition temperature (640°C). Wynn¹⁵⁴ in the 1940's and early 50's postulated that ignition was caused by piezo-electricity but Powell et al¹¹⁶ showed that ignition occurred well behind the pick and the delay was too long for an electrical discharge to be involved. Powell in various research reports has shown conclusively that
 - (a) *Ignition of methane-air by a pick cutting rock occurs at or near the rock surface after the pick has passed.*
 - (b) *Ignition is caused by the hot material left behind by the pick and is likely to be at temperatures exceeding 1200°C.*

(2) Rock Types Involved In Frictional Ignitions. Recent research by Ward et al¹⁵¹ has indicated that high ignition risk can be associated with some conglomerates due to an abundance of hard, homogenous and often siliceous lithic fragments, as well as, if not instead of quartz grains. Frictional sparking was also observed in rocks rich in feldspar, mica and clay but the phenomena of sparking and gas ignition are not necessarily related. What is beyond question in the literature is that two general categories of rock can be identified as causing frictional ignitions - those containing quartz and those containing pyrites. The accepted facts are:

(a) the type of rock most likely to cause ignitions will have a quartz content greater than 30%, a particle size greater than 10 μm and usually greater than 70 μm and the characteristic that it retains its strength at temperatures of at least 1250°C

(b) the rocks described above, when pressed against a grindstone wheel will produce yellow to white heating and afterwards show the remains of a molten patch of fused quartz

(c) when blunt or badly worn picks impact on nodules of iron pyrite, the fine dust created oxidises rapidly and this self-heating can result in ignitions of methane. The strata must contain an appreciable percentage of iron pyrites before this occurs and rock containing less than 10% iron pyrite can be considered safe (Blickensderfer et al⁹).

(3) Speed of Cutting. The effect of the speed at which a pick moves through rock has been investigated by several authors. The influence of this parameter on sharp, blunt and pre-heated picks has been investigated. In general, increasing pick speed produces a greater area of hot spot behind the pick and this leads to an increased probability of ignition. The conclusions reached are

(a) cutting speed has a major influence on the risk of ignition. Pick speed should be reduced to 1,5 m/s or preferably 1 m/s to cause a significant reduction in the risk. This phenomenon holds true for sharp and blunt picks but not for pre-heated picks, where air-cooling has an important effect

(b) at low speeds wear of the cutter picks is minimised and sharp picks have a very much lower chance of igniting methane-air mixtures.

(4) Cutter Pick Forces. Because South African coals are harder than most, the work rate per pick can be between 30 and 40 kW and cutting speeds are about 3 m/s. These conditions generate high stress levels between picks and the material being cut. Lewis⁸¹, Larson et al⁷⁷ and Roepke¹³⁰ have independently concluded that deeper cuts, which involve high power throughputs, are potentially more incendive than shallower cuts with lower power throughputs.

(a) It is apparent that deeper cuts require higher forces, both in the direction of cutting and normal to the pick. With increasing normal force the friction between tool and rock increases. This causes the hot spot to form on hard rocks and creates the conditions responsible for self-heating of pyrite.

(b) Cutting forces can be significantly reduced by using sharp tool and by optimising their design. Tool geometry is, therefore, an important factor in reducing frictional ignitions.

(5) Optimum Pick Design. Although there is frequent reference to pick shapes in the literature, two researchers have been dominant in this area - Powell¹⁰⁹ in the United Kingdom and Courtney³⁶ in the United States. Hardman⁵⁹ has summarised their findings as follows:- "Powell has proposed design guidelines for coal cutting picks that are aimed at reducing the frictional ignition hazard. Although the major coal producing machine in the UK is the coal shearer, and this is the type of machine at which the guidelines are aimed, some of the research finding should be just as applicable to continuous miners. According to Powell, 'limited evidence' has shown that large radial attack picks appear safer than small tools but that some of the best results have been obtained with forward attack picks. The worst results were obtained with wide-bodied point attack picks. From the point of view of reducing the ignition hazard, Powell recommends a forward attack pick, at least 22 mm wide, as the preferred pick with wide radial picks as the second choice.

Experiments have shown that tungsten carbide tips can produce ignitions but the steel body of the pick produces ignitions far more easily. For this reason it is preferable that the tungsten tip is 'oversize' to afford some protection to the pick body. A more suitable and economical material than steel for the pick body has not yet been found. Powell also recommends large round nosed tips of tungsten carbide, covered by a layer of polycrystalline diamond. Figure 1 shows the pick types used in the experiments reported by Powell and Figure 2 is the preferred shape as ascertained from the experimental results. Courtney reports the beneficial results of ignition tests using tungsten carbide capped point attack tools (mushroom tipped tools). Such tools were recommended by the USBM as the preferred tool for use on continuous miners.

Powell has summarised the known facts on pick design as follows:-

- (a) Ignitions occur when a pick wears and then rubs on quartzite rock, producing heating. Although ignitions can and do occur from rubbing of the tungsten carbide tip on the rock, most ignitions are caused by the body or shank steel rubbing against the rock.*
- (b) Larger ("mushroom") tungsten carbide tips delay the onset of ignition, but still do not prevent ignitions.*
- (c) With tungsten carbide tips, the shape or type of pick is important. The point attack or conical pick has an inherently blunt shape and causes ignitions much more easily than radial or forward attack picks that have defined cutting edges.*
- (d) Wide-bodied point attack picks cause ignitions slightly more easily than narrow-bodied picks.*
- (e) Large or very large radial and forward attack picks appear to be safer than smaller picks.*
- (f) Rounded clearance faces on tips appear to be safer than those having angular surfaces.*
- (g) To cut rock safely, picks must stand up to rock much better than they do with existing tungsten carbide tips.*
- (h) A polycrystalline diamond layer on the rake face of a tip can make a pick last very much longer and prevent ignitions occurring, even without water.*

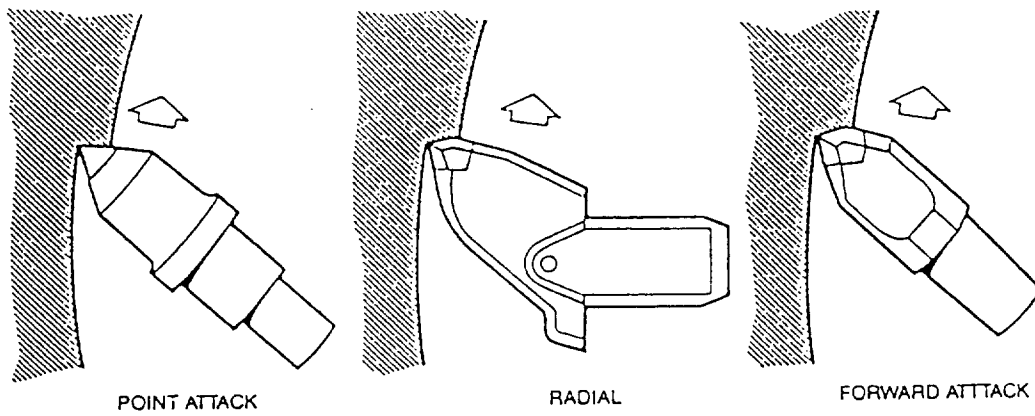


FIGURE 1 Pick Types Used In Experiments Reported By Powell

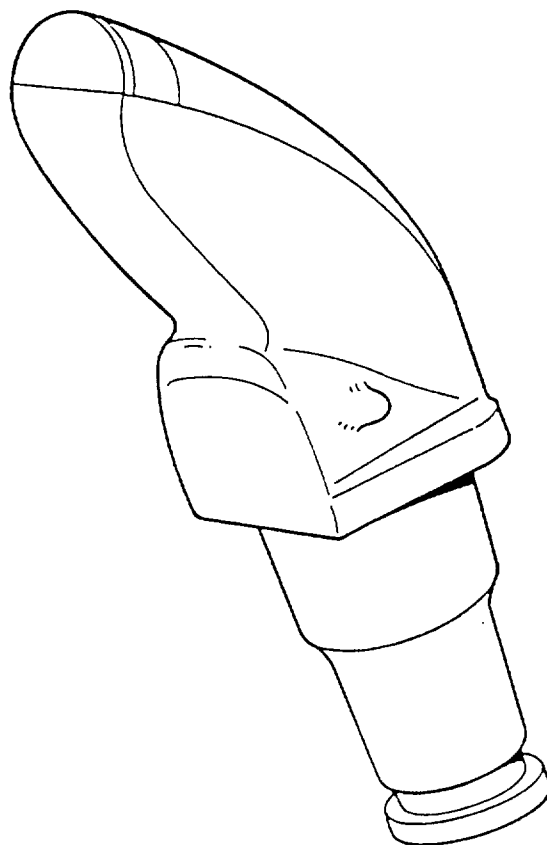


FIGURE 2 Preferred Pick Shape As Proposed By Powell

(6) Effective Prevention of Ignitions. Research has shown that, under conditions likely to produce frictional ignitions, the provision of water jets can have a marked effect. Experimental work, principally by Sapko et al¹³³ and Powell et al^{112, 113 and 114} has shown that there are several ways in which water can work to reduce ignition potential -

- (i) Inertising the mixture of methane and air by the presence of steam and/or fine water droplets.
- (ii) Water sprays perform a useful task in cooling the pick and significantly reducing pick wear.
- (iii) Suppressing any methane/air ignition that might occur before it can propagate and even before it can be observed.
- (iv) Cooling the hot smear of rock/metal left behind in the path of the pick on the rock surface.

Again Powell¹¹⁰ has summarised the research findings very succinctly as:-

- (a) *Water used to prevent ignition must be fed directly onto the hot material left behind the cutting tool at sufficient pressure and in sufficient quantity to cool it quickly.*
- (b) *Water fed to the front of the pick is generally ineffective in producing the necessary cooling. High pressure water in front of a pick is somewhat better.*
- (c) *Water fed through a pick to emerge at or near the tip can be effective, but the exit nozzle stands a high chance of becoming blocked by the material being cut.*
- (d) *The best way of applying water is as a solid spray behind the pick.*

CONCLUSIONS

Research into frictional ignition hazards and their prevention has been conducted continuously since the mid-1920's. Major programmes have been carried out in Germany, Poland, the former Soviet Union, the United Kingdom and the United States, with significant contributions from Belgium, France and several other countries. Since the late 1980's the volume of work has declined very significantly, with only some European Community funded research and an Australian initiative being current. The results of all this research can be characterised as conclusive and repetitious, in that most of the major findings have been confirmed by several research groups working independently.

While metal on metal or rock on rock ignitions are still hazards in modern coal mining, the vast majority of frictional ignitions are situations where small pockets of methane in air are ignited by a spark from a cutting machine. While better ventilation of working faces can significantly reduce the risk of ignition or ensure that any ignition remains a harmless event, with the flame localised and easily extinguished, the potential for disastrous consequences remains with us. While an average of just under 2 frictional ignitions are recorded each year in South African collieries, every effort must be made to reduce the risk of explosions and fires caused by this phenomenon.

The main results of the very considerable body of research that has been devoted to cutter pick ignitions indicate four very important conclusions:

- 1) For a frictional ignition to occur cutter picks must come into contact with strata containing either quartz or iron pyrites. Quartzitic rock must contain at least 30% of fairly coarse quartz grains before the risk of ignition becomes significant. It is, therefore, possible to use petrographic and other analytical techniques to undertake a risk assessment of any site where a machine is to be deployed.
- 2) The sources of frictional ignitions are not sparks but smears of melted quartz that are left of the rock surface as a result of rubbing friction. The risk of frictional ignition rises rapidly when worn tools, which need higher cutting forces and more energy of cutting,

are used. The findings of a number of researchers agree on this issue and the matter has been put very well by Kelley and Blickensderfer⁶⁸

"Worn cutter picks are highly incendive when striking sandstone. This is not caused by the sparks produced - rather, it is a result of a smear of hot material formed on the rock by the impact. As the carbide tip wears down, it becomes more likely to yield the smear and cause the ignition. The likelihood is even further increased after a tip breaks off and the steel shank of the pick rubs against the rock."

It follows from this that one of the most effective precautions against frictional ignitions caused by shearers, continuous miners and coal cutters is to maintain picks in good condition and to change them before they wear excessively.

- 3) Research has shown conclusively that reducing pick speed reduces the risk of frictional ignitions because the length of hot spot also decreases. Because the performance of longwall shearers tends to be limited by the rotational power available to the drums rather than the haulage force, it has been possible to reduce drum rotational speeds significantly, with some machines operating at 19 rpm. The consequent reduction in pick speed has very probably had a major impact on the frequency of frictional ignitions caused by shearers. Continuous miners, on the other hand, tend to be limited by the thrust generated between their tracks and the floor. Experience with modern, heavy continuous miners has shown that rotational speed can be reduced, certainly to 37 rpm, with no adverse effect on production and improved dust readings. However, with a 1 m diameter drum this would still produce pick speeds of nearly 2 m/s, i.e. well above the 1 to 1,5 m/s at which the frictional ignition risk starts to diminish. At the present time, there appears no prospect of continuous miners being manufactured with the required rotational speeds of below 20 rpm.
- 4) The most effective means of preventing frictional ignitions during cutting is to spray water directly behind the pick, parallel to its direction of travel. This quenches the hot spot within the lag time for methane ignition, provided such important criteria as quantity, droplet size and to a much lesser extent minimum water velocity are met. Research has produced proven designs of suppression systems to be used in conjunction with all common types of pick. For many years cutting drums on longwall shearers and some roadheaders have been equipped with phased water supplies, to supply nozzles in front of and behind individual picks. However, wet heads are not yet commercially

available for continuous miners because of technical problems associated with large-diameter rotary water seals.

Finally, it must be stated as a conclusion, that it is impossible to reduce the risk of a frictional ignition to zero, even when the results of research investigations are meticulously applied to the design of picks and cutting drums. An example of this was the Cardowan explosion⁶¹ in the United Kingdom in January 1982. A frictional ignition occurred at a shearer drum, despite the fact that an "anti-ignition" drum, incorporating all known research findings, was in use. A hollow shaft venturi was active and all 29 picks were equipped with water jets, either directed behind the pick or located in the pick shank. The subsequent inquiry determined that "five of these jets were completely blocked and others were partly blocked while several picks were badly worn and one of the standard type picks had lost its tungsten carbide tip." In reality this description could apply, at some time or another, to any shearer or continuous miner in routine production at any mine. Prevention of frictional ignitions must be seen as the first line of defence but also as only one of a series of measures designed to prevent an ignition becoming a serious explosion.

RECOMMENDATIONS

- 1) It is known that the risk of a frictional ignition at any particular site is a function of a large number of factors including:- likelihood of the presence of flammable gas, type and condition of mining machine and presence of quartz and pyrite in the material being cut. Since risk assessment is currently being introduced as a safety management tool for the South African mining industry, it would seem appropriate that a risk assessment should be made for every site at which a cutting machine is to be employed, including classification of any strata likely to be encountered by the picks. Because of privatisation of the British coal mining industry, Owner's operating rules on frictional ignitions⁶² were drafted in 1993 and a great deal of what is said there is relevant, should a similar assessment be required in South Africa. Since the application of precautions against non-existent risk undermines their credibility, risk assessment would allow appropriate levels of precautions at different sites, e.g. where the strata indicates a high risk site in a known gassy seam, it may be appropriate to specify that machines be equipped with a machine mounted active suppression system (if and when the concept is proven). To specify similar equipment at a low risk site in a seam generally free of methane would not only be inappropriate but would devalue the whole concept of risk assessment.
- 2) Recent research by Ward et al¹⁵¹ has indicated that although quartz content is the dominant factor in their ignition category classification (IGCAT), for Australian rocks at least, assessment of frictional ignition potential from mineralogical data requires more than a simple determination of quartz content. Since so little is known of the ignition potential of South African rocks the same may well apply. Either work similar to Ward's should be funded in South Africa or some collaborative effort established. The latter would be more cost effective, would make use of existing expertise and would also allow direct comparisons between South African and Australian coal mining strata.
- 3) The most effective, practical methods of preventing frictional ignitions at the coal face is to use a "wet head machine", with sprays directed behind the cutting picks. There are currently two developments in this area.

Sasol Coal is undertaking trials with a machine equipped with a pump system designed to keep the cutting drum immersed in foam. The main purpose of this is to reduce airborne dust but it has been suggested that it may reduce the ignition hazard. Foam will not have the cooling capacity to quench hot quartz within the time required to prevent ignition and may well have the negative effect of reducing airflow and allowing the methane concentration within the drum to build up. At present this can only be supposition but it is recommended that the results of these trials be made available to the coal mining community for further evaluation.

Joy Mining Machinery in the United States are at present developing a wethead cuttercase for their machines. While wetheads for continuous miners were considered in the late 1970's³³ and experimental heads manufactured in the 1980's, potential customers were unwilling to pay the additional cost necessary to provide a wethead option on a machine. However, in 1995 Joy manufactured a prototype wethead, which experienced teething problems due to the porosity of the castings involved and also with the seals. The latest news (January 1996) is that a new housing and seals have been obtained and testing of the system will begin in early February. Since water sprays behind the cutter picks are undoubtedly the most effective suppression technique, it is recommended that interested parties monitor the progress of this development. Joy Mining Machinery quote the cost of a wethead option as being over \$90 000.

- 4) Research has shown it is extremely difficult, if not impossible, to cause a frictional ignition when using new and undamaged cutter picks. If a risk assessment shows the site to be either a medium or high risk environment, the choice of pick design and the replacement criteria should be based on their potential to cause an ignition. While sophisticated instrumentation is available to analyse cutter head vibrations and warn of damaged or worn picks, a more practical solution in the mining environment is the routine and frequent inspection of the cutterhead by well trained and motivated workers. It is recommended that this aspect of work procedures be reviewed by mines and appropriate attention devoted to this aspect of ignition prevention.

In the longer term it is to be hoped that better tool materials will be developed. Materials harder than tungsten carbide do exist but they have a greater tendency to chip and fracture. The ideal of a non-wearing, non-fracturing material is being pursued by other

industries and the mining industry should not accept that the current generation of tungsten carbide tools are an optimum solution to cutting problems. It is not suggested that the South African coal mining industry should be directly involved in the search for new materials but it can through discussions with tool suppliers and, through constant pressure for improved pick performance, keep in touch with new developments, such as the use of polycrystalline diamond picks¹¹⁰.

- 5) Since there will always be some risk of frictional ignitions, irrespective of whether cutter speeds are reduced to their practical limits and water is supplied to the cutter head (mainly because of the practical difficulty of keeping every device functioning at all times), it is recommended that in high risk situations, means of preventing the spread of ignitions should be used as a second line of defence. Although considerable work has been undertaken in Europe and the United States in the development of active or triggered barriers, either as fixed devices in roadways or mounted on road heading machines, the size of headings in South Africa (up to 6 m high and 7 m wide) and the fact that the majority of our machines are continuous miners, dictates that some further development work is necessary before these devices can be deployed. This work has already commenced at Kloppersbos, where a 20 m long, 7 m wide rectangular explosion gallery has been built for this purpose. Seam heights of between 2 and 6 metres can be simulated by a moveable roof and test work will involve the use of continuous miners and (eventually) roadheaders under near perfect, simulated operating conditions. It is, therefore, recommended that this research is funded at an appropriate level, so that machine mounted active suppression systems (MMASS), which are an important defence against frictional ignitions at a working face (68% of all ignitions and explosions), are available to the industry in the shortest possible time.
- 6) Despite the considerable amount of research into the problems of frictional ignition and the well defined methods of reducing the risk, frictional ignitions still occur at reasonably frequent intervals. Discussions, even with senior mine personnel, have indicated that their knowledge of this subject is somewhat sketchy and inadequate. It can, therefore, be assumed that at the face, the connection between worn picks and a higher risk of frictional ignitions is totally unknown.

In the South African situation improvements in mine safety are most likely to occur as the culture of the mining industry changes from authoritarian to participative. This implies that workers will take greater responsibility for their own safety and must be trained to do so effectively.

The final recommendation of this report is that SIMCOL commissions the preparation of an Information and Training Kit, which explains the phenomenon of frictional ignitions, defines the extent of the problem in South African collieries and gives practical examples of incidents involving frictional ignitions. By emphasising the need to use only picks that are still in a safe condition, to ensure adequate ventilation of the cutting area and to regularly maintain water sprays, an immediate reduction in the risk of frictional ignitions could be achieved.

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