NEW MATERIALS TECHNOLOGY APPLIED IN LONGWALL MINING

By

A.M. James

ABSTRACT

Coal slurry pumping was introduced into the U.K. in 1973. Gateside packs were prepared in areas of containment using R.O.M. coal and a special fast setting cement. The packs restricted roadway convergence and moderated spontaneous combustion risks, but costs were high and alternatives were sought. A similar system using OPC\(^1\) and an accelerator had limited success.

Much more successful was the Aquapack process which used dilute slurries of a special OPC-based cement and an accelerator based on sodium carbonate and bentonite pumped simultaneously into a fabric packbag. The Tekpak system using HAC\(^1\) and a much modified calcium sulphate mixture superseded Aquapack on the grounds of improved cement pumping life, lower alkali content and lower costs. A further modification of this system gave a cement with a 24 hour pumping life thus obviating flushing out pipe ranges except at the week-ends. Improved packbags also increased the efficiency of the process.

The hazard of spontaneous combustion can be inhibited if air supply channels across the waste can be located and plugged. Using gas samples from pack pipes to locate the heating and injecting a special grout, formulated from bentonite, sodium silicate and thixotropic agents, into the waste on the intake road has proved a successful method of controlling heatings.

Mine roadway and face cavities are being safely and successfully filled with cementitious foams produced in a novel placer machine. The foams are based on fast setting cements with specialised foaming agents. Up to 13 cu. metres per hour of fast setting thixotropic foams can be produced and their use is now widespread throughout U.K. coal mines.

\(^{1}\)OPC equates to Ordinary Portland Cement.

HAC equates to High Alumina Cement.

Mr. A.M. James is Managing Director of Foseco Technik Limited.

INTRODUCTION

Modern mining techniques applied to long wall faces and thick seams not only call for innovative high technology in machinery and hardware, but also for new materials and their application. Roadway support systems must maintain the integrity of the roadway and must also be capable of keeping up with the rate of advance. Materials must be kept to a minimum, particularly close to the face end. Transport is costly, thus, material that can be piped effectively to a working area must lead to improved efficiency and low costs. The aim of this Paper is to describe advances in packing systems technology and their related materials, which have helped bring about many benefits which would have been undreamt of 10 years ago.

With the mining of thick seams the ever-present danger of spontaneous combustion in the waste is exacerbated. Materials Technology has again aimed at the development of a system which is becoming standard practice in combating this problem.

Many attempts have been made in the past to find a suitable safe and cheap method of filling cavities. Various organic foams have been used and technically and economically these were acceptable. Problems however with fumes, particularly formaldehyde, encountered during placement and also the feasibility of poisonous gases being given off during spontaneous combustion situations, finally caused rejection of this solution. However, Materials Technology again solved the problem and self-setting inorganic foams can now be produced. The chemistry of the materials and the method of manufacture and placement of these foams will be discussed in this Paper.

MONOLITHIC PUMP PACKING

Perhaps the most dramatic input of Materials Technology has been achieved in the field of gateside packing, where monolithic pump packing has made an immense contribution to the improvement of roadway stability. It has also provided an impervious roadside barrier for the prevention of air leakage across the waste, with consequent reduction of the risk of spontaneous combustion problems.
Monolithic pump packing is, by definition, a term applied to roadside packs which are formed usually by the pumping of two slurries into an area of containment. It is the chemistry of the types of slurries that has seen the major advances of Materials Technology.

Historically, the first pump pack system in the U.K. was the Thysen coal slurry method introduced to the South Wales Area in 1973. The system uses 1:1 ROM coal fines in one slurry and a rapid hardening cement in the other. The coal fines are obtained from an outbye coal transfer point which may be up to 2000 m from the face. Here, the fines are mixed in a purpose designed unit with bentonite and pumped through a 4" main back to the packhole. The cement slurry, on the other hand, is made up at a mixing station usually less than 300 m outbye from the coal face. The rapid hardening proprietary cement has a pumping life of only 15 min. or so, hence the need to keep pumping distances short. This cement is a blend of OPC and special high alumina cement which is, to some extent, catalyzed and given a flash set by the sodium carbonate in the bentonite present in the coal slurry.

The two slurries are mixed at the packhole via a 'T' piece dispenser incorporating a static mixer and contained by brattice lined shuttering or a purpose built moveable shield. Leakage of the liquid slurries is prevented by brattice cloth or filled sacks above the shield. The whole pack becomes self supporting after approximately 2 h. with compressive strengths of 0.3 to 0.4 MPa. Strengths increase rapidly during the next 24 h. to a maximum of approx. 1.3 MPa. Thereafter strengths increase very gradually up to a possible max. of 2 to 2.8 MPa. The pack requires approx. 700 kg of coal fines, 300 kg of cement and 40 kg of bentonite per m³. Slurry water which can vary considerably makes up the balance of the volume, some 350 to 400 litres. It is perhaps of interest to note that the standard bentonite used originally had a high free sodium carbonate level which aided its dispersion and setting when introduced into the coal slurry.

Despite the high initial capital cost of the high capacity coal slurry pumps, pipework and cement mixing station, it was shown that the monolithic packs had very favourable strength properties when compared with other existing packing mediums. The high initial strength supported the immediate roof measures and later controlled the subsidence as the bridging beds began to tower. It is important to note at this stage that pack strengths should only resist the closure pressures to the extent of keeping the immediate roof intact and not exceeding the bearing strengths of the floor. This latter point is particularly important in later pump packing developments where water flushing of extended pipe lines became necessary.

The basic concept of monolithic pump packing had been introduced and the benefits in roadway support and the prevention of spontaneous combustion became self evident. This, together with its facility for being independent of coal face operations made the system attractive, particularly as contract working ensured efficient initial operation.

Coal slurry pump packing spread rapidly to other areas and a maximum of some 100 installations were sold to the Coal Board during this growth period. Inevitably, however, attempts were made to improve and cheapen the system. Difficulties were encountered in organising and providing adequate supplies of coal fines and costs also were looked at in detail. Early installations were rented, contract labour was seen to be expensive and the coal filler aggregate was also costed as initial hopes of using dirt as a filler did not always materialise.

In order to move away from the relatively expensive proprietary cement and also contracted obligations to Thysen, Mines Research and Development Establishment, in conjunction with the Warwickshire Coal Field, developed the Warbret system. This is basically the same in principle as the Thysen, but OPC was used as the cement slurry with the advantage of cheapness and longer pumping life. However, in order to achieve reasonable setting times an accelerator needed to be added to the coal slurry and it was further shown that pre-slurrying the bentonite improved the pumpability of the coal, particularly in the presence of the accelerator. This accelerator, designated TEA.S1, was a blend of bentonite, sodium carbonate, a well known flash setting agent for OPC and triethanolamine. The Warbret system found only limited acceptance and suffered from the same drawbacks as the Thysen process, regarding high initial capital cost and the use of coal fines as aggregate.

The next development was really a quantum jump in technology with the introduction in 1978 of the Monopack system by M.R.D.E. The earlier work with Warbret showed setting times with OPC could be considerably shortened. Further work indicated that using a combination of cements derived from work done by Loosler, the setting of the cement slurry with very high water contents could be achieved. The cement combination used was OPC, MPAC and anhydrous calcium sulphate. In the correct proportions these cements produced the mineral ettringite $3Ca_3(SO_4)_3Al_2(CO_3)_3$ as indicated in the formula. ettringite contains 52 mol. of water and has long needle-like crystals. See Fig.1.

---

2 $3Ca_3(SO_4)_3Al_2(CO_3)_3$ is chemically $3Ca_3O_3Al_2O_33CaSO_4.32H_2O$. 

The AusIMM Illawarra Branch, Ground Movement and Control related to Coal Mining Symposium August 1986 241
Under certain conditions this mineral can also be formed in ordinary civil engineering concrete structures and is known as the cement bacillus.

Fig.1 Electron Micrograph X38000 of Ettringite Network Structure

The setting reaction can be catalysed by a sodium carbonate addition such that setting times of 15 to 20 min. can be achieved and strengths of 0.35 MPa obtained after 2 h. and 2.7 MPa, after 7 days. Most interestingly however, these strengths were obtained with w:se ratio of 1.7:1 and the key to this enormous water holding capacity was ettringite. The long needle-like crystals formed an interlocking structure which acted as a hydraulic sponge. The actual chemically combined water in the crystals only account for a minor proportion of the water absorbed.

Thus, we have a cement system and an accelerator system both capable of being slurried with large quantities of water and which, when mixed, will give adequate strength development properties. For reliability of setting time and pumping life of the cement, it was found necessary to incorporate a small addition of citric acid, which acted as a retarder, giving the slurry a pumping life of approx. 20 mins. and also improved the strength properties. This system originally called Monopack was given the new name of Aquacent. The accelerator system was a 50/50 blend of sodium carbonate and bentonite, which would accelerate the setting of the cement system and also hold the particles of cement in suspension until thickening occurred. This component was named Aquabent, and dilutions of the two systems were such that they could be pumped as a 50/50 mix through separate hoses into a prepared packbag. Slurry mixing was achieved by simply suspending the delivery pipe into the bag and splash mixing. Mixing and delivery of the slurries themselves was carried out, for the cement component in a continuous cement grout mixer sited within 300 m. of the face and for the Aquacent, which was far less critical, a simple paddle mixer was required and this was sited some 1500 m. outbye. Uniform delivery of the two slurries was required for optimum results and ram pumps were usually employed.

A finished pack contained approx. 150 kgs. Aquacent and 50 kgs. of Aquabent per m², but this represents a mere 15% in vol. terms of the pack, the balance of 85% being water. Even so, strength characteristics proved eminently acceptable and support densities of the new system proved adequate. The packs also provided an element of yield whilst being compressed thus providing an excellent ventilation seal and giving constant resistance to convergence forces. These technical advantages were reinforced by the system having no requirement for coal as an aggregate and machinery costs were halved in comparison to the Thyssen pump pack system.

As a result the Aquapack system spread rapidly and gained wide acceptance in mines with advancing faces and thick seams. Modifications to the mixing and pumping equipment were made as initial work which had shown that 'colloidal' mixing of the Aquacent gave improved results, was later found not to be necessary. Inevitably problems arose, not least being, loss of pipework due to setting of the Aquacent in the range. Causes for blockages were manifold, foreign bodies, water supply problems, machine breakdown and inadequate flushing of the range after completion of packing. Pumping stations for Aquabent and Aquacent were usually widely separated and communications could be interrupted with the consequent effect on slurry volumes and pumping rates. The high alkalinity of the products also gave causes for concern and problems with cement skin burns increased. Although costs had improved over the Thyssen pump pack system there was a need to improve the situation even further and it was at this stage that the Fosco Technik Tekpak system was introduced.

The new Tekpak system was introduced in August 1982. Rigorous evaluation trials were carried out until the Christmas period. Development work at Fosco Technik had shown that by using a high alumina cement, composed mainly of calcium aluminate and ferrites, as one component of the slurry pump pack system and the beta anhydrite form of calcium sulphate with catalysts and bentonite suspension agent as a second slurry, it was possible to achieve rapid and high pack strength development at the very high w:solids ratio of 2.5:1. In vol. terms this now meant that the pack was 91% water.

Tekcem and Tekbent, as the products were called, were used in equal quantities as opposed to the 8:1 (weight:weight solids) ratio previously used with Aquapack. One m³ of pack was shown to...
to contain 182 kgs. of Tekcem and 182 kgs. of Tekbent and the specific gravity of this mixture was 1.25 gms/cc. The Tekcem was a specified type of Climent Fondu with a pH in water of approx. 10.3 and it was non-aggressive to the skin. The set time of Tekcem in dilute slurry form was much longer than that previously used and a pumping life, under all mixing conditions, of at least 3 h. was achieved. The Tekbent slurry also had a low total alkalinity and a pumping life in excess of 24 h.

Despite the high dilution rates employed and the longer pumping life of the Tekcem component, reactivity of the mixed slurries was high, the packs being easily self-supporting within ½ h. from completion of pumping.

It was found that Tekpak permitted a wider use of equipment. The longer pumping life of Tekcem allowed simple batch mixers to be employed as with the Tekbent. The pumping station could be moved further outbye, with Tekcem and Tekbent mixing taking place at the same location. This also enabled the use of a back-to-back ram pump which more effectively controlled proportions of the two mixes.

At the packbag it was discovered that the Tekpak system required more positive mixing than the splash mixing which had proved adequate for Aquapack. The juxtaposition of the two components in Tekpak is necessary in order to maximise the formation of ettringite. X-ray diffraction data and electron microscopy of solidified Tekpak showed clear evidence of the efficacy of good mixing and also the preponderance of ettringite in the Tekpak system. Initially, a metal 'Y' piece was used to effect mixing at the packbag but it was later found desirable to use an internal 'trouser' like' flap mixing valve sewn into the packbag. This had the additional benefit of acting as a non-return valve so that bags could be pumped tightly against the roof.

Although the new system had many advantages, one salient point did however recur and that was the continuing necessity to flush out pipe ranges after each pack. This problem was further exacerbated by the longer pumping distances made possible by the extended pumping life.

Earlier in the paper it was stated that pack strengths should only resist the closure pressure to the extent of keeping the immediate roof intact and not exceeding the bearing strength of the floor. Despite care in flushing out techniques, such as stopping mixing operations before completely filling the packbag, or flushing out via a steel tube into the waste, considerable amounts of water still found its way to the gate end floor. Water not only weakens the floor but also gives rise to poor and sometimes dangerous working conditions. A cement slurry with a 24 h. pumping life was required to restrict flushing out operations to week-ends only. This system was introduced in October 1984 and was designated Tekpak XX.

The guidance performance parameters remained the same for the new system in terms of strength development and in fact proved to be somewhat superior. See Fig.2.

Fig. 2 Laboratory work had ensured that the set retardation of the cement slurry was well in excess of 24 h. and settling out and packing of the heavy cement particles was overcome. This was achieved by a combination of organic polymers. Equally important and more difficult was the modification of the Tekbent recipe such that the reactivity with the retarded cement was unimpaired and strength development of the pack maintained. Originally, a slight reduction of water/binder ratios to 2.0:1 was necessary to meet these criteria, but modifications have now taken place which allows the standard dilution of 2.5:1 to be used. Routine flushing out of pipe lines has now been eliminated, thus alleviating the problem of excess water at face ends. The extra cost incurred through the necessity of producing a formulated cement component was to some extent ameliorated by the savings obtained by eliminating flushing out. The 24 h. pumping life increased the overall flexibility of the system. No priming of the cement range was required so that packing was immediately on tap. On completion of the pack, the pump was simply switched off and valves closed. Pumping stations could be moved even further outbye with all the attendant benefits of transportation. Flushing out the range and equipment at week-ends has been shown to be acceptable and provides good housekeeping standards. The XX formulation has now completely replaced the old system.

Recent work has shown that pumping the slurries down the pit shaft is feasible. Settling does occur, but fluidity has been maintained even after standing for 24 h. Pumping distances well in excess of 4000 m. are now being operated and the exciting prospect of pumping from the surface down 700 m. of shaft and along 6000 m. of roadway is close to realisation.

The AusIMM Illawarra Branch, Ground Movement and Control related to Coal Mining Symposium August 1986
SPONTANEOUS COMBUSTION CONTAINMENT

The mechanism of spontaneous combustion in coal mines is well understood. The method of treating the problem however varies considerably according to mine conditions and area established practice. The method to be discussed in this paper has proved successful in the UK, and depends on the injection of a specialised grout into specific areas of the waste.

The location of the heating is crucial before action can be taken and this is accomplished by analysis of gas samples from sample pipes which are placed every 50 m through the packs into the waste. At time of expected incidents, sampling frequency is increased and extra pipes are sometimes necessary to pin down the area of heating accurately. Experienced showed, that if the heating was tackled by grout injection in the intake gate opposite the position where high samples had been found, in the return, air leakage across the waste was usually curtailed and the heating controlled. Part of the success of this method lays in the specialised grout injected into the waste. Bouguelying, as the injection of bentonite gel was known, had been carried out for some time and although the straight clay gel gave reasonable results, a much more effective gel could be obtained by combining the bentonite with sodium silicate, tetrasodium pyrophosphate which acts as a disperseant, and lime. When combined in the correct amounts and well dispersed in a paddle mixer, the gel thickened to a much higher viscosity than the straight clay and provided a good seal when injected into the waste. See Fig. 3.

A single bag mix was required to obviate transport, manufacture and quality problems. This was produced in 1980 under the name of Geolith. Protracted evaluation trials were carried out and these were completely successful. The product was so designed that rapid dispersion would occur even under low shear mixing conditions, with progressive gelation into a stiff thixotropic paste on placing. For easy and consistent production of the gel in the paddle mixers 1 x 25 kg bag of material was mixed with 40 gals. of water. Twin mixers were usually operated with a single ram pump and optimum mixing time was approx. 3 min., which coincided with the tank emptying times. Thus, continuous pumping from the batch mixers could be maintained. Continuous mixers are now being used and calibrated accordingly.

Pumping distances for the grout depend on requirement, but distances of 1000 m, are common and the slurry has been pumped 3000 m, through 1" pipe range.

Geoilth has been applied to most areas where air leakage is a problem. As indicated, the main usage is in the filling of voids and passageways in the waste which are acting as channels for air flowing towards a heating. It can also be used to fill loose ground and cracks which may have formed around a ventilation stopping. The gel remains plastic and will thus accommodate movements in the strata and waste without cracking. Filled pipes can be left and provided they are not open to the atmosphere can be re-used weeks later, thus, in conditions of high spontaneous combustion risk, permanent Geoilth stations with attendant pipework can be set up. The gel will shrink and crack however if left open to the atmosphere, but this is not the condition of use, nevertheless, some loss can occur over a period of several months and a short topping up operation can then be carried out if necessary. This would, of course, be impossible with a fully solidified grout.

With the increase in monolithic pump packing the problem of heatings has been considerably reduced, however the specialised bentonite grout has proved a reliable and useful weapon in the armory of the Ventilation Engineer.

MINES CAVITIES

Geological faults, wash-outs and rock falls give rise to cavities over roadways and on the coal face. The modern wide beam powered supports make access to the face cavities difficult and using timber chocks to support the cavities is a dangerous operation. Many approaches to this problem have been made, such as welded wire mesh boxes, mattresses filled with fast setting cement and the injection of light weight expanded minerals, such as vermiculite and perlite. None of these approaches have led to long term acceptability.
Foams were an obvious answer and both organic and inorganic products have been evaluated. One trial was carried out in the U.K. with polyurethane foam and the results were disastrous. This material is now banned from British coal mines. Far better results however were obtained with a proprietary urea formaldehyde foam named Roschaum. This product is similar in chemical constitution to that used in cavity wall insulation and had been widely used as a ventilation control in German mine roadways. However, although used successfully in several applications in U.K., acceptance of the product was finally refused due to problems of formaldehyde emission during placement and also after gallery trials showed that there was a possibility of evolution of poisonous gases in a heating situation.

One of the first inorganic foams tested was based on sodium silicate and although safe to use proved technically unacceptable. Cementitious foams were the next obvious choice and development work was commenced in 1982 at M.R.D.E., using for reference criteria laid down for the specification of an inorganic foam by an N.C.B. working party in 1981.

The main objectives indicated were that the foam should be incombustible, thixotropic and cost less than £20 per m³. It should be simple to manufacture, non-hazardous and develop strengths of approx. 0.07 MPa after 1 h at a density of approx. 0.2 gms/cc.

The product Aquasil which was a blend of the quick setting cement Aquacem and accelerator Aquabent combined with foaming agents, was the result of this product development. The foaming machine was a modification of the standard placer machine but with a high capacity mono pump in line with the slurry trough. This pump pulled both slurry and considerable quantities of air through into the delivery hose and shear forces and turbulence broke down the air and slurry into a fine structured foam. Between 8 and 12 m³/h of foam could be produced from a single machine. The method was simple, cheap and effective. Large volumes of foam could be produced from minimum quantities of product, expansion rates were in excess of 10:1 and the success of the system was assured with more than 300 foam machines being sold into British coal mines.

However, despite this success problems were experienced due to the alkaline nature of the cement blends used in Aquasil. The surface active foaming agents could defeat the skin causing lowering of protection against the alkaline and sensitive skins could become subject to cement burns.

Using Tekpak technology a foam cement based on high alumina cement has now been produced. The product Tekfoam has been shown to be tolerant of a wide range of water/solids ratios which in turn improves the yield. See Table 1.

<table>
<thead>
<tr>
<th>Water/solids ratio</th>
<th>1.25:1</th>
<th>2.5:1</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wet density kg/m³</td>
<td>0.3</td>
<td>0.22</td>
</tr>
<tr>
<td>Max. compressive strength MPa</td>
<td>0.33</td>
<td>0.11</td>
</tr>
<tr>
<td>Max. compressive strength psi</td>
<td>50</td>
<td>15</td>
</tr>
<tr>
<td>Set time at 20°C/Min.</td>
<td>6</td>
<td>8</td>
</tr>
</tbody>
</table>

It has a pH of slightly over 11.0 and as such is non-aggressive to the skin. Care has also been taken to reduce dust in the product in order to make it more environmentally acceptable in mine roadways. Another interesting development is the use of separate slurries of Tekcem and Tekbent normally used in the pump packing operation. These separate slurries are pumped into the slurry trough of a modified grout placer and a drip feed of foaming agent is allowed into the trough. The slurry and foaming agent are then pulled through into the delivery hose by a high capacity mono pump as in the standard foaming machine. Good strength, but slightly dense foam is produced which is suitable not only for cavity filling but has been used for back filling behind arches and ventilation seals.

**CONCLUSION**

Materials Technology has been shown to be a vital constituent in solving mining problems. Improving working conditions and increasing productivity. The placement of gateride packs with slurries pumped from thousands of metres on the surface is feasible and using these slurries as foams for cavity filling and backfilling of arches has also been achieved.

We must now look towards increasing the strength and scope of these systems and look at Materials Technology also for solving the major environmental problems, such as dust suppression and the use of mine waste underground.

**REFERENCES**


11. HALSE G. Imperial College of Science and Technology. Private communication and photo micrographs.

The AusIMM Illawarra Branch, Ground Movement and Control related to Coal Mining Symposium August 1986

246