EVALUATION OF THE STRENGTH BEHAVIOUR OF MONOLITHIC PACKS

By
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ABSTRACT

Monolithic packing systems have gained in popularity as a gate side packing method. However, there has been no detailed investigation to assess their underground strength behaviour. This work includes the laboratory and in situ investigation for strength behaviour determined on various monolithic packing materials namely Tekpak-XX, Hydropak-20, Hydropak-30, Astrapak-3R, Flashpak, Thysran pack and Aquablends.

A simple technique for assessing the pack strength was developed at the laboratory by using a penetrometer, of which penetration resistance can be directly correlated with the uniaxial strength of the pack. The in situ strength investigations were made on core samples obtained from three pipes inserted inside the pack, while the penetration test were made on the pack surface. The in situ results indicated that the packing material develops an inconsistent strength on various part of the pack which was mainly related to an inadequate mixing of grouts inside the pack.

1 INTRODUCTION

Since their introduction in British Coal mines in the early 1970's, monolithic packing systems have gained in popularity as a gate side packing method. This has been primarily due to the advantage of faster pack construction in comparison to conventional packing systems which require the involvement of manual labour in the pack construction, and the ability to achieve the ideal pack design requirements, that thus reduce the risk of spontaneous combustion. Also, it prevents excessive lowering of the roof above the pack, offers effective bridging of strata across the roadway, and finally it prevents leakage of ventilation air into the goaf. Figure 1 shows the function of an ideal pack to meet strata control requirements and how a badly formed pack contributes to poor strata control of gate roadways.

Figure 1 General closure characteristics of a gate roadway (after Whittaker et al. 1980)

In past years several monolithic packing systems have been developed and used. Various laboratory studies have been carried out to determine comparative performance of monolithic packing systems and results have indicated that pack strength changes with curing time, curing methods, method of mixing various grouts in the two component packing systems and shape and size of specimens. These factors may present major difficulties in extrapolating the laboratory evaluated strength results to in situ pack strengths. It is therefore necessary that pack strength should be determined in situ and should be correlated to the gate roadway performance.

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The in situ performance of packs have also been assessed by measuring the load on them using load cells and measuring pack convergence in relation to distance from the face line. Several studies have also been carried out to assess the overall stability of gate roadways through utilizing various monolithic packing systems by using roadway deformation survey techniques, Uner (1988). However, no in depth studies have been carried out to investigate in situ strength properties of monolithic packs which provided the basis for this research. This paper summarizes detailed investigation into the in situ and laboratory strength behaviour of various monolithic packing systems used by British Coal. It is also concerned with the development of a simple technique for the assessment of in situ pack strength.

2. REVIEW OF PUMP PACKING SYSTEMS

In the past 18 years or so, several monolithic packing systems have been developed and used. In addition, laboratory studies have also been carried out in an attempt to utilize colliery mining with powdered Fuel Ash (PFA), cement and accelerators, to form gate roadway packs, Zadeh et al (1987). The monolithic packing systems currently in use in British Coal mines are the following:

2.1 Tekpak - is a most popular system of monolithic packing. A typical Tekpak packing system consists of the following mixture by weight:

- Tekone 14.5%
- Tekbonet 14.5%
- Water 71.4%

Tekone and Tekbonet are mixed with water then pumped separately at a ratio of 1:1 from a nearby pumping station to the pack-hole. The two slurries are then mixed together inside the pack-hole through a 'V' nozzle built within the packing bag.

2.2 Hydropak - is a successor to Tekpak made by Fosroc. It has with a high strength characteristic with the cement and accelerators having a minimum pumping life of 24 hours.

2.3 Flashpak - is British Coal development in pump packing systems. A slurry composed of Powdered Fuel Ash, bentonite, and accelerator is prepared at a surface mixing station and pumped underground by a 150mm pipe line. The cementitious components (ordinary Portland cement - OPC and water) are slurred some 200-300m outby of the coal face is pumped to the packhole by another pipe line. The two pipe lines are combined by a mixing nozzle at the pack-hole and the pack is constructed by spraying the mixture, layer upon layer and allowing the pack material to set almost immediately in a confined space defined by a "U" shaped steel shield connected to hydraulic roof supports on the coal face.

2.4 Thyssen system - was the original pump packing system developed in the UK in 1973 and was first used at Cwms-Coedy Colliery in South Wales. It consists of an out-by aggregate pumping station and an in-by gate mixing station. Run of Mine (ROM) product is screened to -19 mm and stoned in a bunker in sufficient quantity for the construction of a pack. ROM is mixed with flowcrete, bentonite and water to form a slurry, also a second slurry of a quick setting cement 'Packbind' is prepared in a nearby station to the coal face. Both slurries are pumped to the pack-hole and the two pipe lines are combined by a mixing nozzle at the pack-hole. This system presents the disadvantage of using expensive ROM coal as an aggregate and puts more load on the colliery transport system.

2.5 Astrapak - is manufactured by Fosroc Ltd to replace Aquapak and claims to offer superior loading characteristics. It consists of the following components by weight:

- Asmecum 14.3%
- Asmabeet 14.3%
- Water 71.4%

The pumping stations and pack constructions are similar to that of Tekpak.

2.6 Aquablenda - is a one mix packing material containing one part Aquablenda and 1.7 part water. The mixture contains 37% solid and 63% water.

3. LABORATORY ASSESSMENT OF DIFFERENT PACK STRENGTH

Studies done by the present authors and previous workers have indicated that the strength and deformation properties of various monolithic packing material, changes according to the method of mixing grits in the two component packing systems, curing time, curing methods and shape and size of specimens. In recent years, the British Coal Corporation has specified pack design requirements as shown in Table 1.
Table 1  Pack design requirements (after Clark and Newson, 1985)

<table>
<thead>
<tr>
<th>Curing time (Hours)</th>
<th>Strength (MPa)</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.1</td>
<td>Pack self supporting requirement</td>
</tr>
<tr>
<td>2</td>
<td>0.4 - 0.5</td>
<td>Equivalent tensile of a power-support</td>
</tr>
<tr>
<td>24</td>
<td>1.0 - 1.4</td>
<td>Yield strength of face support</td>
</tr>
<tr>
<td>Final</td>
<td>6.0 - 10.3</td>
<td>Prompted by measured load on packs under various field conditions</td>
</tr>
</tbody>
</table>

The laboratory testing programme has been made on both cubic and cylindrical samples to establish a relationship between cubic and cylindrical strengths. This would facilitate the reporting of in situ test results in terms of a customary cubic strength as required by British Coal.

Briefly, the two solid components of the pack material are mixed separately with water using a Hobart mixer at 50rpm for seven minutes. The two slurries are then mixed together until they become thick and then cast in 50mm, 65mm, 100mm cubes and cylindrical moulds of 50mm, 65mm and 100mm diameters with a length to diameter ratio of 2.5. Experience has shown that both ends of the moulds should be hermetically sealed to preserve water and heat of reaction within the sample. If heat and water losses were permitted during the initial stage of curing, the samples would develop poor strength with time.

The cast samples were removed from the moulds after 2 hours, 24 hours and 7 days. After specimens were removed, they were tested immediately for strength determination using a Denison Hydraulic testing machine. Two sets of samples were tested for each curing time and the mean results were calculated. Also, from the same batch of specimens, several samples were used for the penetrometer testing. (One sample set consists of total of 56 samples, six of each 50, 65, 100mm cubes and 50, 65 and 100mm cylindrical core samples).

A penetrometer has been deployed in this investigation in an attempt to develop a method for indirect evaluation of the pack strength. It is a very versatile and convenient instrument with which to measure the penetration resistance of soft materials, concrete and unconsolidated soil. Penetration tests using 3, 4.5, 6 and 9mm diameter needles were used for rapid estimation of the pack strength. The penetrometer needle is pushed at a rate of 2.5mm per second inside the pack. The corresponding load, as indicated on the stem of the penetrometer, is recorded. The resistance to penetration (the mean of 10 to 50 penetrometer readings on each sample) is then correlated with the uniaxial strength of the pack as determined on cubes and cylindrical samples.

3.1 Laboratory Results and Discussion

Table 2 summarises the uniaxial compressive strength for cylindrical and cubic samples of various monolithic packs. The tests were conducted on different specimen sizes as determined in the laboratory for curing periods of 2 hours, 24 hours and 7 days.

(a) Effect of water temperature. Figure 2 shows the effect of water temperature on the strength development of 65mm cubes of Tekpak cured at different periods. With a water temperature of 20°C, the initial strength rise was slow, but when the water temperature was 25°C and 30°C, the initial strength development was quicker, and after a 24 hour curing period, the strength development levelled off. The seven day strength of Tekpak was highest for a 20°C water temperature and lowest for 30°C.

Preliminary studies in the laboratory have shown that if water temperature is lower than 20°C, it adversely affects the curing of monolithic packing materials. However, if the water temperature is below 15°C, the two slurries tend to settle down quickly allowing clear water to rise at the upper part of the mould. This causes the packing materials to set unevenly leaving most parts of the cast sample very weak. Consequently, a water temperature of 20°C was used throughout the laboratory studies.

![Figure 2  Relationship between pack strength development at different water temperatures](image)
Table 2: Summary results of packs strength at various specimen sizes and shapes

<table>
<thead>
<tr>
<th>Pack type</th>
<th>Curing time (hours)</th>
<th>Cube strength (MPa)</th>
<th>Cylinder strength (MPa)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>50 mm</td>
<td>65 mm</td>
<td>100 mm</td>
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<tr>
<td>Tekpak-XX</td>
<td></td>
<td></td>
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</tr>
<tr>
<td>2</td>
<td>0.63</td>
<td>0.78</td>
<td>1.01</td>
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<tr>
<td>24</td>
<td>1.72</td>
<td>2.08</td>
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<td>168</td>
<td>3.38</td>
<td>3.45</td>
<td>3.66</td>
</tr>
<tr>
<td>Hydropak-20</td>
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<td></td>
<td></td>
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<tr>
<td>2</td>
<td>1.05</td>
<td>1.41</td>
<td>1.65</td>
</tr>
<tr>
<td>24</td>
<td>3.23</td>
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<td>3.33</td>
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<tr>
<td>168</td>
<td>3.30</td>
<td>3.42</td>
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<tr>
<td>Astrapak-3R</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>0.49</td>
<td>0.67</td>
<td>0.69</td>
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<td>24</td>
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<td>2.24</td>
<td>2.29</td>
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<td>168</td>
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<td>Aquablends</td>
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<td>0.47</td>
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<td>5.22</td>
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<tr>
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<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>0.37</td>
<td>0.38</td>
<td>0.36</td>
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<td>0.51</td>
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<td>0.37</td>
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<tr>
<td>168</td>
<td>0.75</td>
<td>0.69</td>
<td>0.51</td>
</tr>
<tr>
<td>Flashpak</td>
<td>samples not solidified</td>
<td>samples not solidified</td>
<td>samples not solidified</td>
</tr>
</tbody>
</table>

(b) Time dependent strength. The results indicate that all monolithic packing materials increase their strength with time. However, the rate of time dependent strength growth is different for different monolithic packing materials. A logarithmic strength development with curing time was observed in the cases of Hydropak, Tekpak, Flashpak and Astrapak, whereas Aquablends and the Thyssen Pack follow linear time dependent strength characteristics. Table 2 shows that for two hours curing time Hydropak develops the highest uniaxial strength of 1.33 MPa whereas the Thyssen system develops the lowest average strength of 0.30 MPa. The trend for the development of 24 hour strength is the same as that of 2 hour strength. Hydropak again develops the highest strength of 3.35 MPa whereas Tekpak, Astrapak, Aquablends, and Thyssen developed an average strength of 2.0, 1.98, 1.50 and 0.37 MPa respectively. A significant change in the strength values of packs occurred for a curing period of 7 days, especially in the case of Aquablends which developed a strength of 5.52 MPa, while for Tekpak and Astrapak a strength of 3.4 and 2.4 MPa was developed. However, it may be noted that Hydropak developed a peak strength at 24 hours curing time that remained the same after 7 days curing time. Flashpak develops very poor strength for 2 hours, 24 hour and 7 day curing time although its long-term strength is considerably higher than other monolithic packing systems.

(c) Shape effect on monolithic pack strength. One of the main objectives of the laboratory study was to develop empirical relationships between cube and cylindrical strengths of various monolithic packing materials. Those relationships can then be used to evaluate the cube strengths of the packs obtained from the cored cylindrical samples from the underground packs. The relationship between cubic and cylindrical specimen strengths for various monolithic packing materials shows linear relationships with high degrees of correlation coefficients. Those relationships are summarised as follows:

- Aquablends:
  Cube strength = 0.865 × Cylindrical strength (MPa)

- Astrapak-3R:
  Cube strength = 0.10 + 1.225 × Cylindrical strength (MPa)
Flashpak:
Cube strength = \(-0.14 + 1.2964 \times \text{Cylindrical strength (MPa)}\)
Hydropak-20:
Cube strength = \(-0.15 + 0.575 \times \text{Cylindrical strength (MPa)}\)
Tekpak-XX:
Cube strength = \(-0.03 + 1.013 \times \text{Cylindrical strength (MPa)}\)
Thyssen Pack:
Cube strength = \(-0.02 + 1.515 \times \text{Cylindrical strength (MPa)}\)

(d) **Effect of specimen size on the strength developments.** Relationship between specimen size and uniaxial strength on both cylindrical and concrete samples revealed two distinct trends. For Tekpak, Hydropak, and Astrapak, the strength increases with an increase in specimen size particularly between the specimen size 50mm and 65mm, while the strength of Thyssen pack and Aquapak reduces with an increase in specimen size. These trends are evident for all samples at curing times of 2 hours, 24 hours and 7 days (Table 2). In the case of the Thyssen pack, the strength reduction can probably be attributed to lack of specimen homogeneity as it consists of Run of Mine (-19mm) material, while the increase of strength with specimen size for Tekpak, Astrapak and Hydropak can be attributed to the retention of the heat of reaction due to a larger sample mass.

(e) **Penetrometer readings and pack strength.** There are strong linear relationships between the uniaxial strength and penetrometer results of the various monolithic packings as illustrated in Figure 3. However, the penetrometer readings for the Thyssen pack show a wide scattering (figure not shown), which is mainly due to the presence of Run of Mine material as part of the packing system which in turn produces a high resistance to the penetrometer needle during the test. Hence the penetrometer can be utilized to assess all the various pack strengths except for the Thyssen system.

4. SITE INVESTIGATION

The underground investigations were intended to cover the assessment of the packs’ strength and penetrometer results after curing periods of 2 hours, 24 hours and 7 days for the Tekpak-XX, Astrapak-3R, Hydropak and Flashpak. Penetrometer tests were carried out on the surface of the pack, whereas uniaxial compressive strength tests were conducted on cores obtained from the PVC and steel pipes using the portable tester. Testing of each packing system has been carried out at two different mixes with the exception of the Flashpak.

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Figure 3 Relationship between different packing strength and penetrometer readings

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system which was only used at the Parsonage Colliery. The visited sites include Annexley, Cauferton, Manor., Beverley, Rossington and Markham Main Collieries.

4.1 In situ sample collection - Initially it was planned to use a hydraulic drill incorporating a double core barrel for drilling a borehole in the pack to obtain core samples for the strength test. An underground drilling trial at Annexley Colliery showed that the core samples obtained from the pack were heavily cracked, joined and very poor in appearance and hence not suitable for strength testing.

A new method of obtaining an intact sample has been specially developed for collecting pack material at various depths in the pack at different curing periods. This was to insert three pipes (two of PVC and one of steel) into the pack whilst the grouts were filling the packhole. When the pipes were filled and the pack solidified, core samples could be obtained from the pipes.

4.2 Pipe design for the collection of pack sample - The design of the PVC pipe was simple, it consists of two concentric PVC pipes open at both ends. The two pipes are separated by four 'O' rings (two at each end) to hold the inner pipe in position, and also to prevent the ingress of packing material between the two pipes which would cause trapping of the inner PVC pipe after pack solidification. The inner pipe is 10 cm longer than the outer pipe towards the outside of the pack, the extra length being used to facilitate gripping the pipe for withdrawal. As the tests have to be conducted at various curing periods, it is necessary to replace the outer PVC pipe with a steel pipe which is required to remain inside the pack for 7 days to protect the inner PVC pipe from damage due to load generation on the pack from gate closure.

4.3 Pipe installation and sample collection from the pack - Since the pipes have to be installed in the bag during the pumping of the grouts, it was found necessary to provide external reinforcement around the pipe insertion holes in the pack bag to prevent bag rupture. This was achieved by gluing a square piece of perspex on to the bag wall which contained a hole at the centre to fit the outer diameter of the PVC or steel pipe. A hole was made in the pack bag through the centre hole in the reinforcing plate.

The perspex plates were affixed at the centre of the pack bag at three different heights (approximately 70, 120 and 150 cm above the floor) and pipes inserted in the bag as illustrated in Figure 4.

The first pipe inserted in the pack is the steel pipe, which is pushed inside the pack for half its length and held slightly dipped toward the outside of the pack. When the pack slurry started to overflow from the outer end of the pipe, the pipe was then pushed more fully inside the pack leaving about 30 cm outside to permit the pipe to be held horizontally and the outer end of the pipe is then sealed by a wooden plug to contain the slurry. After two minutes the plug was twisted and partially removed allowing any air trapped inside the pipe to escape so ensuring that the pack material fully occupies the pipe. A similar procedure was followed for the installation of the other pipes inside the pack.

![Figure 4 Schematic diagram showing relative sample location inside the pack](image)

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4.4 Core sample preparation - After 2 hours of installing the upper pipe (Figure 4), the inner pipe holding the sample is pulled out and cut into segments. The relative sample depth of the pack hole were recorded to study the change in strength behaviour from the pack surface to the middle of the pack hole. Each core segment was 165mm in length and 66mm in diameter, providing a core sample with a length to diameter ratio of 2.5. The sample encasing PVC pipe is then split longitudinally along a prepared groove using a sharp knife. The core sample is then tested for uniaxial strength after both ends of the core were flattened and made parallel to each other. Similar procedures were followed for obtaining core samples from the 24 hours and 7 days PVC pipes. The in situ assessment of the uniaxial strength was conducted on a portable modified point load testing machine. This method of obtaining core samples from the pack has been successfully used at all the investigated sites without problems of bag rupture.

4.5 In situ strength investigation - Summary results of the in situ strength behaviour for various monolithic packings are illustrated in Figure 5. The diagrams show the relative sample strength from the pack surface to the pack centre at curing periods of 2 hours, 24 hours and 7 days.

Penetrometer measurements were conducted on different parts of the pack surface. Further penetrometer measurements were then made on different packs at the gate roadway. It is however, difficult to quantitively assess the pack strength by penetrometer tests because of the fact that the penetrometer tests were carried out on the stronger part of the pack; whilst the poorly cured part of the pack was found to be too weak to respond to penetrometer tests.

Figure 5  Relative sample strength and location inside the pack for various packing materials at different curing periods

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Teknok-XX. The in situ strength results from Annesley and Markham Main Collieries indicate significant increase in pack strength towards the pack centre for samples cured at 24 hours and 7 days. This phenomenon could be explained by the retention of heat of reaction inside the pack providing catalytic strength growth of the pack. While no such change in strength behaviour occurred for samples cured at two hours, this could be due to the time lapse being insufficient to build up heat inside the pack. Heat loss on the outer surface of the pack results in the development of lower strengths at the gate roadway’s edge. The temperature of the FVC pipe was observed to be considerably higher towards the centre of the pack, so much so that it was almost impossible to handle the installing pipe with bare hands even after seven days of curing.

(a) Markham Main Colliery. The average cube strength at Markham Main Colliery after 2 hours, 24 hours, 7 days and 28 days were 1.77, 0.53, 1.93 MPa respectively. The pack strength measured at two hours was about three times the strength of 24 hour, and was of similar strength to the 7 day sample strength. The gradual increase in pack strength toward the pack centre could indicate that the two grouts are mixed well inside the pack. However, the inconsistency in the pack strength at different height could only be related to a variable delivery of the two grouts to the pack-hole.

(b) Annesley Colliery. The in situ strength measurement programme at Annesley Colliery was carried out twice. During the first investigation, inadequate mixing of the two grouts was observed, thus the pack developed weak and inconsistent strength, with samples that were partially solidified. Hence, only a few samples could be tested giving average cube strength of 0.31, 0.96 and 1.82 for 2 hours, 24 hours and 7 days curing period respectively. With a slight modification to the arrangement of the sturme boxes inside the pack during the second underground investigation, the pack showed a dramatic increase in strength. The average cube strength and Young's Modulus after 2 hour, 24 hours and 7 days were 0.72, 2.55 and 2.72 MPa and 0.039, 0.215 and 0.308 GPa respectively. The rise in the pack strength and the obtaining of good core samples could only indicate a well mixing of the two grouts, this however, does not mean that the two grouts are mixed in equal proportion.

Penetrometer tests conducted on the pack surface (from Annesley and Markham Main Collieries) showed a wide range of values which reflect the variable pack strength at various parts of the pack. Inadequate mixing of the two grouts was observed in most of the pack holes on the gate roadway. Visible evidence on parts of the pack revealed that areas which had a dark grey colour had high strength values, whereas other parts with a light grey colour had low strength values.

Flashpak. The in situ investigation of Flashpak strength at Parnsonage Colliery shows that the pack does not develop any significant strength even after 3 days of curing. The packing material remained very plastic and did not appear to be suitable for strength testing. Also, due to vandalism, the steel pipe for the 7 day test programme became inaccessible. Consequently, no strength test has been carried out on a cylindrical core specimen. Instead, large pieces of the packing material were chiselled from the pack face and cube specimens were prepared for testing. The cube strength varied between 1.7 to 4.6 MPa, and this inconsistency in the pack strength can be attributed to the poor and inhomogeneous mixing of the two grouts. This is well shown on the pack surface where an irregular pattern of dark and light colour bands corresponded to the poor mixing between the FPA slurry and cement grout. Also, the pack appeared cracked and heavily jointed, hence the likely distribution of micro fractures within the samples which resulted in variable strength of different samples. Finally, it was observed that the Flashpak material contained numerous air cavities varying in size from less than a millimeter to over 50mm in diameter. The air is most likely trapped during the process of splash mixing, therefore the random distribution of these air cavities within the tested specimen will have great influence on the sample strength.

Penetrometer tests on the pack surface proved unsuccessful. After a curing period of three days, the Flashpak material had still failed to develop sufficient strength to register a significant reading on the penetrometer even when the instrument was used with its largest needle (40mm in diameter). Most surprisingly and in complete contrast, the test after 7 days curing revealed that such a marked increase in strength had subsequently taken place that even the smallest penetrometer needle (2mm in diameter) was now unable to penetrate the pack material. It seems therefore that the penetrometer instrument cannot be usefully employed for indirect assessment of the pack strength for the specified curing periods of 2 hours, 24 hours and 7 days.

Hydropack. The mining operation conducted on the High Hazel coal seam from Calverton Colliery is 1.2 meters thick. As the pack was not high enough to insert three pipes as originally planned, the three pipes were installed separately in three different bags at different dates.
The major trend of the pack strength shows weakening toward the pack centre. Also, fluctuation in the pack strength was detected from adjacent samples cured for 24 hours and seven days (Figure 5). This reflected the poor and inhomogeneous mixing of the two grouts inside the packhole. However, the average in situ cube strengths were 2.32, 2.99 and 2.87 MPa, and the Young's Modulus values were 0.248, 0.349 and 0.397 GPa for the 2 hours, 24 hours and 7 days curing period respectively.

It was observed that the mixing tank for Hydrobent retained 15 to 20% of the grout whilst the other tank for the Hydrocem grout had totally discharged its contents, hence at the end of each mixing batch the remaining Hydrobent was pumped alone to the pack, this resulting in the formation of the weak zone in the pack. In total there are three weak zones in each packhole which correspond to the number of batch mixings necessary to fill the packhole.

Penetrometer readings revealed a very low pack strength in the above mentioned regions. Average penetrometer measurements on other parts of the pack were similar to the laboratory results at various curing periods. However, as the pumped ratio of the two grouts in the packhole were not equal (grout mixture containing more Hydrocem than Hydrobent), the in situ penetrometer result cannot be compared with the laboratory result, as the two mixtures components ratio are not the same.

Hydropak-30 The in situ investigation showed that the pack strengths are inconsistent at different parts of the pack. The two hours core sample was partially consolidated toward the face of the pack, and only three samples were able to be tested for the 2 hours period. Similar to Hydropak-20, adjacent core samples from the same PVC pipe shows differing pack strength which reflected poor grout mixing, despite that there was a trend of pack strength increase toward the pack centre (Figure 5). The average cube pack strength and Young's Modulus developed after 2 hours. 24 hours and 7 days period were 1.05, 2.77 and 1.54 MPa and 0.153, 0.192 and 0.181 GPa respectively; it appears that the 24 hours pack strength developed twice the pack strength of seven days.

It was observed that the grout components were pumped into the pack at variable ratio due to poor maintenance of the mixing tanks and inadequate quality control. It may be noted that the hydrocem mixing tanks were clean and well serviced, whilst the hydrobent mixing tank together with the impeller was found to be heavily coated with the congealed slurry resulting in a reduction of more than 22% of the tank capacity. Despite that, however, the operators continued to mix four bags of hydrobent to a marked tank level with water. This obviously produced a denser hydrocem slurry, which in turn was difficult to mix with a less dense hydrobent slurry.

Penetrometer tests conducted on the pack surface provided a wide range of measurements, indicating poor grout mixing and variable pack strength.

Astrapak-3R

(a) Roroting Colliery. The in situ investigation revealed that the packholes developed consistent strength at the pack surface as indicated by the penetrometer readings. However, the upper part of the pack shows a wider scatter in the readings which can be related to the poor mixing of the two grouts.

The average pack strengths and Young's modulus after 2 hours, 24 hours and 7 days curing periods were 2.41, 2.99 and 3.75 MPa and 0.19, 0.24 and 0.41 GPa respectively. There was no change in pack strength behaviour towards the pack centre for all the curing periods tested (Figure 5), apart from one sample which (sample No 1, 2 hours curing time) developed weaker strength due to the presence of weakly solidified grouts, reflecting poor grout mixing.

(b) Maton Colliery The packhole provided at this site was surrounded on all the sides by a metal shield 1.8 meter in height. The only access for testing the packing material was the confined space between the roof and the top of the metal shield which were about 0.4 meter in height and 1.2 meter in length. Hence the three pipes were inserted side by side in the upper part of the pack.

The whole core contained in the 2 hours PVC pipe was found unsuitable for strength testing due to partial solidification of the packing material inside the pipes. Core samples obtained from the second PVC pipe (24 hours pipe) were also found partially solidified and unsuitable for the strength testing. However, in situ strength measurements were carried out on a few core samples obtained from the inner end of the third pipe. The number of core samples tested for the curing periods of 2 hours, 24 hours and 7 days were two, three and two respectively as illustrated in Figure 5. The average in situ cube strengths and Young's modulus are 1.78, 4.12 and 4.37 MPa and 0.31, 0.39 and 0.33 GPa for the curing periods of 2 hours, 24 hours and 7 days respectively. The high strength developed after 24 hours and 7 days does not reflect the true strength of the whole packing system and this could
possibly be due to a higher ratio of Astracem in the grout mixture. The remaining three core samples from the outside of the pack (cores no 8, 9 and 10, Figure 5) were found to be partially consolidated, indicated by the difference in colour between hard and soft material in the core. Their in situ cube strength was 3.06, 0.86 and 0.25 MPa, the decrease in the core strength towards the outside of the pack being due to a higher proportion of liquid grout within the core. The in situ investigations at all the visited sites revealed that the upper part of the pack for the two grout components does not develop good strength presumably due to reduced splash mixing potentials.

The penetrometer test showed a wide variation of measurements at the pack surface, again indicating the inconsistent mixing between the two grout components. The poor mixing encountered at this site precludes useful comparison of core strength tests and penetrometer results.

4.6 Summary of in situ investigation

The in situ investigations into the pack strength at Annesley, Markham Main, Calverton, Bevercote, Rostingdon and Manton Collieries revealed the following:

1) The two grouts are often pumped at different ratios within the pack.
2) The water to solid ratio is more than pack design recommendation.
3) The pack develops variable strength at different parts of the pack due to the inadequate mixing of grouts inside the pack.
4) Although the in situ strength of the core specimens shows consistency inside the PVC pipes, the final result cannot be used to reflect the overall pack strength.
5) In situ penetrometer investigation on packing material along the gate roadways indicates that the Tekpak-XX, Astrapak-3R, Hydropak-20 and Hydropak-50 monolithic packing system become weaker with time due to the loss of their water content. The exception was the Flashpak system where the pack material retained its strength even when all its water had been lost.
6) Laboratory calibration of the penetrometer cannot be used for assessing the in situ pack strength due to the inadequate mixing of the grouts and the poor sample homogeneity within the pack. This is part explains why the in situ penetrometer readings show a wide scatter. Therefore, in situ penetrometer measurements can only provide a comparative strength assessment for different parts of the pack.

7) Without exception the pack strength developed at the upper parts of the pack are weak. Consequently, the packing material will not provide immediate support to roof above the pack as it should do.

4.7 In situ observation on pack strength behaviour - Common underground observations on the packing construction revealed that if the pack strengths are weak and inconsistent it could be due to the combination of the following reasons:

1) Inadequate grout mixing inside the pack can be observed as:
   a) Partial consolidation of the grouts mixture at different parts of the pack, particularly at the upper part of the pack.
   b) The penetrometer measurements at the pack surface are variable and shows a wide range of readings within a short distance of measurements.
2) Different ratios of the pumped grouts are indicated by variable strengths developed at certain bands within the pack.
3) More water to solid ratio than being recommended shows the following:
   a) The mixing grouts will take a longer period of time to set.
   b) The pack will appear to remain wet for a longer period of time.
   c) Pockets of water trapped between the solidified pack material and the packings' bag can be felt by hand.
   d) The pack will develop a low strength.
   e) The penetrometer readings on the pack surface will be very low.

5. RECOMMENDATIONS

In view of the variable development of the monolithic pack strength behaviour the following recommendations are made:

1) It is highly recommended that the two grouts should be mixed through a mixing nozzle before the delivery to the pack to ensure sample homogeneity. A proper mixing arrangement is shown in Figure 6.
2) The water to solid ratio should be strictly used as recommended by the manufacturers. Therefore, a much higher standard of supervision and quality control at the mixing station for grout construction is desirable.
Figure 6 The proposed arrangement for the installation of a mixing nozzle

3) Constant maintenance and cleaning of the mixing tanks is required to ensure a correct water to solid ratio in the tank.

4) The pumping ratio of the two grouts should be monitored to ensure a constant volume delivery of both grouts to the pack.

5) It is highly recommended that a review to the proportion of constituents employed in the Flashpak system should be made.

References


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