Safety in Mines Research Advisory Committee

Optimisation of Support in Collieries
(a continuation of SIM020205)

Final Report

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Executive Summary

In order to eliminate fall of ground accidents, Safety in Mines Research Advisory Committee (SIMRAC) initiated a research programme to investigate the roof support systems that are currently being used in South African collieries. The aim of this programme was to gain an understanding of the fundamental mechanisms of roof support systems and to develop guidelines and design methodologies for their improvement.

SIM 020205 investigated all of the currently available elements of roof bolt support, along with their related installation machinery. These were tested underground in three different rock types, namely sandstone, shale, and coal. The current project, SIM020205b is aimed at:

- Quantification of the effect of parameters that were identified by SIM 020205 as important in roof support system performance.
- Development of guidelines for testing procedures to achieve the maximum support performances as recommended by SIM 020205.
- An improved roof bolt installation technique.
- Development of new resin quality control and testing procedures.

The findings of these two projects will also be incorporated into a booklet, entitled “roof bolting guidelines for South African collieries”.

SIM 020205 highlighted hot and cold rolling of steel as an important parameter in controlling the performance of a support system. In the current project, it has been established that the hot rolling process of bolt manufacture is preferential for use in the coal mining industry. This is because hot rolling produces a more consistent product in terms of the bolt's dimensions, i.e. core diameter and rib height. From underground short encapsulation pull tests, it is found that hot rolling gives a better performance in terms of grip factor and stiffness when compared to bolts manufactured using the cold rolled process.

“Finger gloving” is one of the most discussed topics of roof bolting. “Finger gloving” occurs when the Mylar cartridge wrapper remains intact around the hardened resin. This prevents the resin from completely bonding to the rock. In order to determine the severity of this phenomenon, a series of test installations were carried out in Perspex tubes to observe
the quality of resin mixing when using different installation methods. These observations revealed that “finger gloving” occurred, to a greater or lesser extent, in almost all installations. It was found that more “finger gloving” was likely to occur if the bolt was pushed through the resin capsule before spinning took place. Whilst underground SEPT identified a slight difference in the performance of bolts installed in this method, indicating a higher percentage of finger gloving, the difference was not great enough to be alarming and still comfortably passed recommended support requirements. It is therefore concluded that “finger gloving” is present in most installations but has little effect on the performance of the system.

A new support design methodology, using “height of fracturing in the roof”, was developed and summarised in the final report of SIM020205. This new methodology highlighted the importance of the shear strength of roof bolts that are currently being used in South African collieries. Laboratory shear tests were therefore performed on full column resin roofbolts, indicating that the shear strength of roofbolts is approximately 89 per cent of the ultimate tensile strength of the bolt, which is significantly greater than the previously assumed 50 per cent of tensile strength. It is established that the shear strength of 20 mm roof bolts currently being used by the steel supplied by ISCOR is approximately 213 kN.

SIM 020205 identified roofbolt installation as an area, which must be investigated. Four different types of installation were identified, namely:

- Flat end bolt spun through resin;
- Flat end bolt pushed through resin, then spun;
- Angle end bolt spun through resin;
- Angle end bolt pushed through resin, then spun.

Visual observations on the quality of resin mixing in each method were carried out. It was observed that when bolts, either flat or angle end, were pushed through the resin capsule before spinning, then a displacement of the catalyst took place. The catalyst is less viscous than the resin in a resin capsule and so when a bolt is pushed through the capsule, the less viscous material is displaced to the bottom of the hole. This effect is increased by gravitational effects in vertical holes. Mixing of resin and catalyst cannot take place properly therefore reducing the effectiveness of the support.
In addition, underground short encapsulation pull tests were conducted to quantify the effects of the different methods. The results showed that whilst differences in grip factor were minimal, large differences were found when comparing the stiffness of a system. In tests done for both 15-second and 30-second resins, grip factors for an angled bolt pushed through the resin before spinning were the poorest for both resin types. The other three installation methods performed identically well. In terms of stiffness, the flat end bolts outperformed the angle end bolts, with a flat end bolt spun through the resin capsule giving the best performance. It is therefore concluded that the best installation method to use is a flat end bolt, spun through the resin in order to achieve a stiffer roof support system.

Pull tests were also conducted on resins of various ages to determine the effect of expiry upon performance. It was established that performance of the system is reduced as the time increases past the expiry date. A resin, which had expired by 6 months, gave 33 per cent poorer performance than a new resin.

In order to determine a resin testing procedure, a series of tests were conducted using the testing facilities at Anglo Coal Rock Engineering Laboratory. Resins of different ages were tested. The results indicated that the older the resin, the lower the torque achieved. This indicates that a torque test could be a quick and easy method of determining expired resin.

Additional tests were conducted to determine whether resin gel time could be used to determine expiry of a resin but the results proved inconclusive.

The effects of over or under spinning of resin were observed and the effects quantified. It was established that under spinning of a 15-second spin to stall resin still provided results within the acceptable limits of performance. For a 30-second resin, over spinning resulted in reduced performance and it was concluded that a 30-second resin should not be spun for more than 20 seconds no matter how slow the spinning speed.
It is stated that laboratory testing is not appropriate to determine the performance of a roof bolting system to be used in an uncontrolled environment. It is therefore suggested that the performance and the quality control tests of roof bolt systems should be conducted underground in the environment where the roof bolts will be used. A simplified short encapsulated testing procedure is suggested, which eliminates the time consuming measurements which are taken in detailed SEPT. It is suggested that the measurements taken from the bolt, resin capsule and hole diameter can be eliminated without jeopardising the quality of test results.
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1.0 Introduction

A proper roof support system is a function of the rock mass, bolt, hole and resin characteristics, as well as the characteristics of bolt accessories (nut, thread, washer). The recent SIMRAC project, SIM 020205, entitled “An investigation into the support systems in South African collieries” investigated all these elements of the roof support systems used in South African collieries. However, SIM 020205 also highlighted a few new considerations that needed to be taken into account in achieving the best support system in different environments. These considerations were:

- A series of quick-and-easy testing procedures to determine the performance of support elements.
- Installation of roof support.
- An evaluation of newly developed resin testing procedures.

Discussion with the coal Rock Engineering personnel highlighted that a new series of testing procedures should be identified to determine the performance of support elements, such as the bolt, resin, nut or washer. It was recommended in SIM 020205 that these testing procedures should be developed to assist the coal mining industry to conduct these tests quickly and efficiently.

One other important parameter that affects the performance of a support system is the quality of support installation. It is well known that poor roof bolt installations can result in an inadequate support system, irrespective of the quality of all other elements of the system.

New support installation techniques, such as the “spin-to-stall system”, helped collieries to improve the support installation practice. While the spin-to-stall system provides a simpler underground procedure, it is significantly more demanding on the roof bolting system components. The resin must provide sufficient time for adequate mixing and roof bolt insertion, then transform very rapidly from a liquid to a set state and develop high bond strength. The properties of the resin, the properties of the roof bolt, the breakout torque of the nut and other parameters are important in developing and optimising this new system (O’Connor et al., 2002). An improved installation technique, which will minimise the human error in the installation of support and ensure all components of the bolting system
are synchronised, is therefore required to ensure the correct installation of support to improve the safety of the underground workforce.

SIM 020205 also highlighted that resin is the most vulnerable part of a bolting system. Many investigations around the world found that larger bolt-holes can result in poor resin mixing, a greater likelihood of "finger-gloving," and reduced load transfer capability. On the other hand, narrower holes can result in significant temperature rises during the mixing in the hole, which may accelerate the resin setting, causing gellation before the determined setting time. The previous project, SIM 020205, suggested the use of SABS testing facilities in mines' quality control testing procedure. However, it has been found that resin which passes the SABS tests may fail in underground short encapsulation pull tests. Also, new resin testing facilities have been built by Anglo Coal and Minova in South Africa recently. Therefore, an evaluation of these facilities was conducted to develop a new resin quality control procedure technique that will ensure the expected support performance.
2.0 Quantification of the effect of parameters identified by SIM 020205

A number of parameters were identified in SIMRAC 020205 as important and requiring further investigation. These parameters were:

- Effect of hot and cold rolling of bolts;
- Effect of finger gloving on system performance;
- Shear strength of bolts

A series of tests were therefore conducted to determine the impact of these parameters on the overall roofbolting system performance.

2.1 Effect of hot and cold rolling of bolts

One of the parameters identified in SIM 020205, the Investigation of Support Systems in South African Collieries, as requiring further attention was the affect that hot and cold rolling of steel has on the performance of the bolts. It was thought important to investigate which of these processes produced a better bolt for use in an underground environment.

At increased temperatures, the strength values (yield stress, proof stress, and tensile strength) of metals decrease and they become "softer". Also, the possible plasticity at higher temperatures is greater, as a rule, and the metal becomes more ductile. This change of properties with rising temperatures is used for the hot forming of steel. In general, the temperature for hot forming is higher than the re-crystallisation temperature of the steel.

The resulting advantages of hot forming include:

- Improved formability of the work piece.
- Less force required.
- Large degree of possible deformation in one step, resulting in a reduction of processing time.
- Beneficial effect on the structure and the properties of the work piece.
• Little or no work hardening (if not desired).

Some disadvantages of hot forming are:

• High resource input and related costs for heating the steel in relation to the energy required for forming.
• Inevitable formation of hard and brittle scale on the surface of the work piece and related tool wear.
• Reduced standing time of tools due to the thermal load and increased wear.

It was established in SIM 020205 that Manufacturer A used hot rolling procedures in the manufacture of their bolts, and Manufacturer B used cold rolling. Figure 1 and Figure 2 show the deviation from the average bolt core diameter. It can be clearly seen that hot rolling produces a more consistent bolt than cold rolling.

![Figure 1: Deviation in bolt core diameter, Manufacturer A](image-url)
This trend is repeated when looking at the rib heights (Figure 3 and Figure 4). Hot rolled bolts produce a more consistent product than cold rolled.
Figure 4  Deviation in rib height, Manufacturer B

A comparison of the grip factor and stiffness of hot and cold rolled bolts (Figure 5 and Figure 6) shows that hot rolled bolts outperform cold rolled bolts in both categories. The grip factor of hot rolled bolts was found to be almost 20 per cent greater than that of cold rolled bolts, with stiffnesses of more than double.

Figure 5  Grip factors of hot and cold rolled bolts
All of this evidence indicates that hot rolled bolts are better suited to an underground coal mining environment. It should however be noted that increased pull out resistance and stiffnesses of hot rolled bolts over cold rolled bolts can be attributed to improved dimension control in hot rolled bolts.

It should also be noted that the use of cold rolled bolts in South Africa has become extremely rare, and only one colliery is known to use them. Roofbolt manufacturers supply cold rolled bolts only if requested by the mine.

### 2.2 Effect of finger gloving on system performance

Finger gloving occurs when the Mylar cartridge wrapper remains intact around the hardened resin. This prevents the resin from completely bonding to the rock. There has been much debate upon whether this has a significant negative affect on bond strength, grip factor and system stiffness. A series of tests were conducted to observe the extent of finger gloving in roofbolting. These tests also enabled the impact that the differing installation methods had on the extent of finger gloving to be observed. By cutting open the Perspex tubes, finger gloving could be further observed from an internal perspective. The results can be seen in Figure 7, Figure 8 and Figure 9.
Figure 7 shows an example of poor quality resin mixing coupled with finger gloving. The red line of the resin capsule indicating the use of a 30 second, spin and hold resin can clearly be seen through the Perspex tube. This indicates that a large portion of the resin capsule remained intact after setting.

![Figure 7 Finger gloving in resin sample](image)

By splitting the Perspex tubes, a better impression of the extent of finger gloving can be obtained. Figure 8 shows the empty resin capsule wrapped around the hardened resin, between the resin and the tube. This will clearly prevent the resin from bonding to the tube or, if it were to occur in an underground environment, the rock.

![Figure 8 Internal view of test sample](image)

In Figure 9, the resin capsule can be observed lying above the bolt in the upper portion of the photograph, as highlighted. The capsule appears to still contain a portion of the resin, indicating that incomplete mixing of the product took place.
Because these tests were performed in a laboratory environment, using Perspex tubes, it is accepted that underground conditions are not replicated exactly. A bolt hole underground will provide a rougher, more uneven hole than provided in these tests. Despite this, finger gloving is still likely to occur in an underground environment to some extent.

Figure 10 demonstrates one of the major concerns associated with finger gloving. In this sample, the Mylar capsule has prevented the resin from bonding to the threaded walls of the installation tube. However, this problem has been exacerbated by the removal of the bolt from the test sample so that this effect could be demonstrated. In a real situation, it is felt that the confinement of the hole would force the resin to bond to the profile of the hole, so that whilst the resin may be prevented in places from bonding directly to the rock, support resistance is still provided by the profile of the hole. In this situation, hole profile becomes of paramount importance, a rougher hole providing more resistance to movement.
It is accepted that short encapsulation pull testing could overestimate the influence of the resin capsule, due to the higher relative percentage of capsule material, capsule end effects, and short bond length, when compared to a full column bolt installation. To what extent this is true needs to be established. Throughout all of the test samples, finger gloving was found to be most prevalent when the bolts were pushed through the resin capsule before spinning took place. Finger gloving also took place when the bolt was spun through the resin capsule, but not as frequently.

Results from underground SEPTs installed using the different installation techniques indicated that, whilst there were differences in the performances of the installation techniques, these were negligible. These results can be seen in Figure 11. As mentioned, SEPT will overestimate the influence of finger gloving, so in a full column installation it can be assumed that finger gloving has little adverse effect on bolting system performance.
2.3 Shear strength of bolts

The shear strength of roofbolts is an important aspect in the beam building method of roof support as the bolts generate shear resistance to the movement of the beams within the roof unit. Extensive studies in the past have been carried out to determine the shear strength of a bolt. In South Africa, it has been accepted that 50 per cent of the tensile strength of a bolt is approximately equal to the shear strength of a bolt. However, Azuar (1977) concluded, from tests of resin-grouted bolts embedded in concrete, that the shear resistance of a joint when the bolt is installed perpendicular to the joint is similar to the tensile strength, and about 90 per cent for inclined bolts. Roberts (1995) reported shear test results for smooth bars, rebars and cone bolts. From these tests, Roberts (1995) noted that a grouted 16-mm diameter rebar had a static shear strength of almost 90 per cent of the ultimate tensile strength. The shear strength of a full column resin, 20 mm diameter bolt was assumed to be equal to 80 per cent of the ultimate tensile strength of the bolt in the previous SIMRAC project, 020205, in order to calculate the required bolt length and density of support design calculations.
The current study provided an opportunity to study the shear strength of full column resin bolts in more detail. A number of tests were performed at the testing facility of the CSIR using a 30 second resin with a 20 mm diameter bolt. The bolt and resin were mixed at a speed of 185 RPM and installed into a 28 mm diameter mild steel tube, Figure 12.

![Figure 12 Bolt and resin installed in mild steel tube](image)

A groove was then cut into the centre of the tube to provide a shear plane and lessen the effect of the tube upon the test results. The bolt was then inserted into the shear test rig in preparation for testing. The inserts in the rig which provided the shear plane were made of heat toughened steel. The test rig was then inserted into the Terratek test rig and loaded until failure.

The shear test rig can be observed in Figure 14 as a sectioned schematic. As can be seen, the bolt, resin and tube arrangement are slid inside the shear test rig inserts and the groove aligned in the centre of the rig. The shear test rig and inserts can be observed in Figure 14. There are two blocks within the test rig, one stationary and the other moveable. The moving block slides on four vertical shafts to prevent rotation and ensure the motion is linear. Once inside the testing apparatus, the moving block is pushed down relative to the stationary block, providing the shear stress.
Figure 13  Sectioned schematic of shear testing rig
A total of 10 samples were tested and a set of very consistent results was attained. A typical load – displacement curve for the tests is shown in Figure 15. The results can be seen in Table 1.

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<th>Load (kN)</th>
<th>Displacement (mm)</th>
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<tr>
<td>Average</td>
<td>213.3</td>
<td>16.4</td>
</tr>
<tr>
<td>Maximum</td>
<td>226.0</td>
<td>19.0</td>
</tr>
<tr>
<td>Minimum</td>
<td>205.0</td>
<td>15.0</td>
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<tr>
<td>Standard Deviation</td>
<td>7.0</td>
<td>1.6</td>
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The results indicate that the average shear strength of a full column resin bolt is slightly more than 210 kN and the displacement is just over 16 mm.
Ultimate tensile tests performed at CSIR Miningtek on 20 mm roof bolts indicated that the tensile strength is approximately 240 kN. From these results, it is possible to establish that the shear strength of a full column resin bolt is 89 per cent of the ultimate tensile strength.

This finding is also an important consideration in the design of roofbolting systems in hard rock mining, where the bolts are under continuous shear force in highly jointed rock.

*Figure 15  Typical load-displacement curve for shear tests*
3.0 Roof bolt installation techniques

Roofbolt installation is often a contentious issue, with a number of theories put forward as the correct method of installation. As highlighted at a workshop in the initial stage of the project, the main issues are whether to push the bolt to the back of the hole before spinning, or if the bolt should be spun through the resin whilst the bolt is pushed to the back of the hole.

In a full column resin installation with a long bolt, the resistance of the resin can make it difficult to achieve pushing the bolt to the back of the hole. It was also shown in SIM 020205 that roofbolting machines are not always in the best condition and may not have the required thrust to push the bolt through the resin. In these situations the operator has little choice but to spin at least a portion of the bar through the resin capsule. However, an early start to spinning the resin in a long-bolt installation may result in an over mixing of resin. It is therefore important to determine the optimum spinning and pushing speeds of the bolt through the resin.

Another issue, which necessitates investigation, is the nature of the bolt end. Mines use either a flat ended bolt or an angled end bolt, usually at approximately 45 degrees. A flat ended bolt is suitable for installation of smaller, 0.9 m and 1.2 m, bolts. As the bolts become longer, it becomes more difficult to force the flat end bolt through the resin capsules required for a full column installation without spinning the bolt through a portion of the resin.

The primary reason for using an angled end bolt is to assist in punching through the resin capsule and to shred the capsule’s film. A problem can however arise if the bolt hole is considerably larger than the bolt diameter. This can lead to the resin capsule slipping to one side of the bolt, not puncturing the capsule, and leading to poor quality mixing of the resin and catalyst. Another concern is that of “finger-gloving”, where the bolt pierces the capsule from the bottom and becomes encased within the capsule. Mixing can occur but as the resin does not bond to the rock, in this situation, the load transfer characteristics are debatable.
To determine the effects of different installation methods on the mixing capabilities of a point anchored resin bolt, a series of laboratory tests were conducted using transparent Perspex tubes. Four different methods of installation were tested, namely:

- Flat ended bolt, spun through the resin capsule;
- Flat ended bolt, pushed through the resin capsule then spun;
- Angle ended bolt, spun through the resin capsule;
- Angle ended bolt, pushed through the resin capsule then spun.

Visual observations were noted on the quality of the mixing for each method, before the Perspex tubes were split and removed to allow a more detailed inspection of the mixing process. The tubes were clear Perspex, 500 mm in length, 3 mm thickness, with an internal diameter of 30 mm. Short encapsulation pull tests (SEPT) were also performed underground in a sandstone roof to test the pullout resistance of each method.

3.1 Flat ended bolt, spun through resin capsule

Underground SEPTs determined that a flat ended bolt, spun through the resin capsule whilst being installed provided consistent grip factors of 0.6 kN/mm and the highest average stiffness of any of the tests. Visual observations of three test samples indicated that this method provides the most consistent mixing of the four methods used. Whilst the top 50 mm of the Perspex tube appears to have a marble effect, indicating that resin and catalyst have not mixed correctly, the remaining length of tube shows a consistent grey colouring. This implies that adequate mixing has taken place, Figure 16.
Figure 16  *External observations of flat ended bolt, spun through the resin capsule*

Figure 17 shows a comparison of all three tests performed by spinning the bolt through the resin capsule with a flat ended bolt. The upper and centre tests showed a similar trend; poor mixing at the top of the tube, illustrated by a marble effect mixing, followed by good consistent mixing of resin along the remainder of the tube. The lower test in Figure 17 showed relatively poorer mixing. In these tests, the capsule is visible at the end of the tube, followed by 100 mm of well mixed resin and catalyst. There appears to be a void at the mid point of the mixing and the lower portion again has a marble effect, indicating poor mixing.

*Figure 17  Comparison of mixing with flat end bolts spun through resin capsule*
Figure 18 and Figure 19 show the opened tube with the resultant resin mixing from a flat end bolt spun through the resin capsule. In both cases, a similar trend was observed. The upper portion of the installation showed poor quality mixing with the Mylar being clearly visible in both cases. In Figure 18 the Mylar was seen to be wrapped around the upper portion of the bolt, clearly a result of the process of spinning the bolt through the resin capsule. Figure 19 proved slightly different, a 100 mm length of capsule containing both resin and catalyst can be seen unbroken. Whilst a large percentage of the material had been squeezed from the capsule, it is still largely intact implying that the top 100 mm of the hole is very poorly mixed. Below the top 100 mm, the remaining length of resin and catalyst in both samples is well mixed.

![Figure 18](image1.png)  
**Figure 18**  
*Internal observations of flat end bolts spun through resin capsule*

![Figure 19](image2.png)  
**Figure 19**  
*Internal observations of flat end bolts spun through resin capsule*

### 3.2 Flat end bolt, pushed through resin then spun

A flat end bolt pushed through the resin to the back of the hole before spinning is shown in Figure 20. In this case the resin can be seen pushed to the back of the hole and appears to be poorly mixed with catalyst. At the bottom of the mix, the catalyst can be clearly seen,
unmixed with resin. This is due to the catalyst being less viscous than the resin before mixing takes place. As the bolt is pushed through the resin capsule, both resin and catalyst are displaced. The catalyst, being of lower viscosity, is pushed to the bottom of the hole leaving only a section of approximately 100 mm in the middle providing adequate mixing of the resin.

This can be seen in Figure 21. The upper left portion of the photograph shows a consistently dark grey material, indicating that very little catalyst has been mixed with resin. This lasts for approximately 150 mm of the length of the test before a lighter grey, well mixed portion of the sample can be seen.
3.3 Angle end bolt spun through resin

An angle ended bolt which is spun through the resin capsule should provide a similar mix to that of a flat ended bolt. The theory of the angled bolt is that it will tear and shred the Mylar capsule more easily than a flat ended bolt. Figure 22 shows the mixing achieved in this case. As can be seen, the mixing appears to show resin at the top of the tube, followed by approximately 150 mm of well mixed resin and catalyst and a small portion (approximately 20 mm) of relatively unmixed catalyst at the bottom portion of the test tube.

![Figure 22 Angle end bolt spun through resin](image)

Upon opening of the Perspex tube it was found that the Mylar capsule had been wrapped around the bolt, Figure 23. This is to be expected as the film would be pierced then spun around the bolt as it is pushed through the remainder of the capsule. The upper portion of the bolt appears to be well mixed, with only a small percentage of the upper portion showing unmixed resin.

![Figure 23 Internal observations of angle end bolt spun through resin](image)
3.4 Angle end bolt pushed through resin then spun

Angle end bolts pushed through the resin capsule and then spun exhibit similar characteristics to the flat end bolts when installed in the same way. The results can be seen in Figure 24. As with the flat end bolt, the difference in viscosity between the catalyst and resin causes a displacement of the catalyst when a bolt is forced through the resin capsule. This, combined with the added effect of gravity, causes a large percentage of the catalyst towards the bottom of the hole, leading to an imperfect mix between resin and catalyst.

![Figure 24 Angle end bolt pushed through resin](image)

3.5 Quantification of the effects of installation method

In order to quantify the effects of the different installation methods identified, a series of underground short encapsulation pull tests were carried out in near identical conditions in a sandstone roof. Tests were performed using both 15 second, spin-to stall resin, and 30 second, spin and hold resin. For each set of tests a total of 5 tests were conducted and the best of three results were used in the analysis. The results of the tests can be seen in Figure 25 and Figure 26.
Figure 25  Grip factors for 30 second resin in a sandstone roof

Figure 26  Grip factors for 15 second resin in a sandstone roof
These figures highlight that the differences in grip factors obtained from the different installation techniques are minimal. However, the angle bolt which was pushed through the resin before spinning gave consistently poorer grip factors for both resin types. This installation method showed an 8 per cent drop in performance for 30 second resin, and an 18 per cent drop for 15 second resin.

A comparison of the stiffnesses achieved in the tests was also conducted. Figure 27 shows the system stiffness for the various installation methods with a 30 second resin. It can be seen that the tests involving flat ended bolts provided a much stiffer system than angled bolts. Flat ended bolts which were spun through the resin capsule provided a stiffness of more than double that of the flat ended bolts which were pushed to the back of the hole before spinning. Angled bolts provided the poorest stiffness for 30 second resins, with both installation methods less than 20 per cent of the stiffness of the flat bolt, spun through.

![Figure 27 Stiffness of 30 second resin in a sandstone roof](image)

The 15 second resin showed a similar trend in terms of stiffness performance (Figure 28). The flat ended bolts outperform the angled bolts in both sets of tests. Although more
closely matched than the 30 second resin, the flat ended bolt spun through the resin capsule again gave the best stiffness, closely followed by flat end bolts pushed through the resin, then spun.

It should be noted that although large variations in the stiffnesses of each system was observed, they were all within the acceptable limits of a 20 mm roof bolting system (60 kN/mm, see SIM 020205 final project report for details), except the angled bolt pushed through the resin. It is therefore recommended that using an angled bolt and pushing through the resin capsule should be eliminated as an installation method as much as possible to obtain the maximum support performance.
4.0 Resin quality control procedures

4.1 Introduction

Underground short encapsulated pull testing (SEPT) is a method which is frequently used to determine the performance of the support as part of a mine’s quality control procedures. These tests give a good indication of how the support performs in situ, but SEPTs are time consuming to perform and therefore expensive, making them impractical for the routine quality assurance testing of resin. Currently, the resin quality in South Africa is controlled by the “SABS-1534:2002” specification. It has been found, nevertheless, that resin which has passed the SABS specifications may still fail in underground SEPTs. For this reason, testing facilities were required and built by both Anglo Coal and Minova South Africa, with the aim of identifying faulty resin before being transported underground.

4.2 Performance testing of expired resin

Defective resin can be caused by improper storage/transportation (too hot, too cold, too wet, or shelf life exceeded), or (rarely) manufacturing problems.

Manufacturers indicate the expiry date, together with other information on each resin box. These dates are usually determined through laboratory tests at room temperatures in well-ventilated rooms. In comparison, the temperatures in an underground environment can vary substantially. Resin can therefore expire at a different time to that which is indicated on the box.

In order to demonstrate this effect, a series of in situ short encapsulated pull tests were conducted. In these tests, 30-second resin was used and all tests were conducted under near-identical conditions in a sandstone roof. Table 2 shows the expiry status of the resin used.
Table 2  Expiry dates of resin used in SEPTs

<table>
<thead>
<tr>
<th>Batch Number</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>Batch 1</td>
<td>Expired for 6 months</td>
</tr>
<tr>
<td>Batch 2</td>
<td>Expired for 1 month</td>
</tr>
<tr>
<td>Batch 3</td>
<td>Expired for 1 day</td>
</tr>
<tr>
<td>Batch 4</td>
<td>Not Expired</td>
</tr>
</tbody>
</table>

Figure 29 shows the results obtained from underground SEPT. This figure indicates that expired resin may cause a reduction in support performance (up to 33 per cent).

Figure 29  Performance of expired resin
4.3 Torque testing of resin

At Anglo Coal’s laboratory, tests were conducted on 13 different types of resins. The resins had different set times, namely 15-second spin to stall resin, 30-second, 60-second and 5-10-minute (all spin and hold resins) and also had different expiry dates.

Each resin was spun until it stalled, except for the 5-10-minute resin. Due to its long setting time, the 5-10-minute resin was spun differently. It was spun for 10 seconds and then held for 30 seconds, repeatedly until the resin set. Figure 30 explains the method in which the 5-10-minute resin was spun.

![Spin and hold time for 5-10-minute resin](image)

**Figure 30** Spin and hold time for 5-10-minute resin

4.3.1 15-Second resin

An example of a torque graph from a 15-second resin is presented in Figure 31. This resin had 3 months to its expiry date. It can be seen that as the resin starts to set, the measured torque increases, up to its setting point, at which point it rapidly begins to drop.
The results from the testing of 15-second resin are summarised in Table 3. This table clearly indicates that the longer the time after the expiry date, the longer the gel time, and the poorer the resin torque performance.

![Torque test graph for 15-second resin](image)

**Table 3 15-second torque test results**

<table>
<thead>
<tr>
<th>Batch</th>
<th>Torque</th>
<th>Time to set</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>120</td>
<td>14</td>
<td>Not expired</td>
</tr>
<tr>
<td>B</td>
<td>81</td>
<td>16</td>
<td>Expired 1 month before</td>
</tr>
<tr>
<td>C</td>
<td>60</td>
<td>18.5</td>
<td>Expired 3 months before</td>
</tr>
</tbody>
</table>

4.3.2 30-Second resin

An example of a torque graph from a 30-second resin is presented in Figure 32. Similar to the 15-second resin, the 30 second resin was also 3 months away from expiry. The increase and drop-off of torque with the setting of the resin can also be seen with this resin type.
The results from the tests on 30-second resin are summarised in Table 4. Similarly, these results indicate that the longer the time after the expiry date the longer the gel time and poorer the resin torque performance.

### Table 4 30-second torque test results

<table>
<thead>
<tr>
<th>Batch</th>
<th>Torque (Nm)</th>
<th>Time to set (sec)</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>D</td>
<td>75</td>
<td>15</td>
<td>Not expired</td>
</tr>
<tr>
<td>E</td>
<td>65</td>
<td>56</td>
<td>Expired 1 month before</td>
</tr>
<tr>
<td>F</td>
<td>23</td>
<td>Not set</td>
<td>Expired 3 months before</td>
</tr>
</tbody>
</table>

**1.1.1. 5-10-minute resin**

An example of a torque graph from a 5-10-minute resin, which again was 3 months away from its expiry date, is presented in Figure 33. With this resin type, it is more difficult to distinguish the increases in torque due to the nature of the resin setting time. However, it can still be seen that the torque increase with increased setting time.
Figure 33  Torque test graph for 5-10 minute resin

A similar trend to 15-second and 30-second resins was also obtained from 5-10 minute resin.

4.4 Gel time testing

Although Minova SA’s gel tester has been described in detail in SIM 020205 final report, a brief description is also provided here. The Minova gel tester comprises an electric motor attached to a spinning arm. A disposable plastic paddle is inserted into this arm. This is lowered into a hand-prepared resin/catalyst sample and spun. The electric current used by the motor is monitored throughout the spinning process. As the resin gels, the resistance to the motor increases, with a resultant increase in the required current. At a preset current (in milliamperes) the resin is deemed to have set and the test is complete. A plot of the current (mA) versus time is then interpreted to determine the gelling time of the sample.
Tests were performed using Minova’s gel tester on both 15-second and 30-second resins of varying ages, in an attempt to find any variance in set time which could be used to identify expired resin. Both types of resin were tested at ages of one week, one month, three months and six months, and the results were also compared with their original batch results. The results are shown in Table 5 and Table 6.

**Table 5  Gel test results for 15-second resin**

<table>
<thead>
<tr>
<th>Resin Type</th>
<th>Resin Age</th>
<th>Test Number</th>
<th>Gel Time (sec)</th>
<th>Original Gel Time (sec)</th>
</tr>
</thead>
<tbody>
<tr>
<td>15 second</td>
<td>1 week</td>
<td>1</td>
<td>5.0</td>
<td>n/a</td>
</tr>
<tr>
<td>15 second</td>
<td>1 week</td>
<td>2</td>
<td>6.0</td>
<td>n/a</td>
</tr>
<tr>
<td>15 second</td>
<td>1 month</td>
<td>1</td>
<td>6.5</td>
<td>6.5</td>
</tr>
<tr>
<td>15 second</td>
<td>1 month</td>
<td>2</td>
<td>6.3</td>
<td>6.8</td>
</tr>
<tr>
<td>15 second</td>
<td>3 months</td>
<td>1</td>
<td>6.5</td>
<td>4.8</td>
</tr>
<tr>
<td>15 second</td>
<td>3 months</td>
<td>2</td>
<td>6.9</td>
<td>5.0</td>
</tr>
<tr>
<td>15 second</td>
<td>6 months</td>
<td>1</td>
<td>5.5</td>
<td>6.8</td>
</tr>
<tr>
<td>15 second</td>
<td>6 months</td>
<td>2</td>
<td>5.5</td>
<td>6.3</td>
</tr>
</tbody>
</table>

**Table 6  Gel test results for 30 second resin**

<table>
<thead>
<tr>
<th>Resin Type</th>
<th>Resin Age</th>
<th>Test Number</th>
<th>Gel Time (sec)</th>
<th>Original Gel Time (sec)</th>
</tr>
</thead>
<tbody>
<tr>
<td>30 second</td>
<td>1 week</td>
<td>1</td>
<td>13.2</td>
<td>n/a</td>
</tr>
<tr>
<td>30 second</td>
<td>1 week</td>
<td>2</td>
<td>11.5</td>
<td>n/a</td>
</tr>
<tr>
<td>30 second</td>
<td>1 month</td>
<td>1</td>
<td>10.9</td>
<td>9.0</td>
</tr>
<tr>
<td>30 second</td>
<td>1 month</td>
<td>2</td>
<td>11.0</td>
<td>9.0</td>
</tr>
<tr>
<td>30 second</td>
<td>3 months</td>
<td>1</td>
<td>12.0</td>
<td>8.8</td>
</tr>
<tr>
<td>30 second</td>
<td>3 months</td>
<td>2</td>
<td>12.0</td>
<td>9.0</td>
</tr>
<tr>
<td>30 second</td>
<td>6 months</td>
<td>1</td>
<td>10.5</td>
<td>13.8</td>
</tr>
<tr>
<td>30 second</td>
<td>6 months</td>
<td>2</td>
<td>12.5</td>
<td>12.8</td>
</tr>
</tbody>
</table>

Figure 34 and Figure 35 show comparisons of the gel times for both 15-second and 30-second resins. The new test results are those obtained from the recent tests at Minova SA, and the original test results are the initial test results when the batch was first produced. Obviously, for this reason, the 1 week old resin samples for each resin type only have one set of results.
These results indicate little correlation between gel time and age of 15-second resins. Figure 35 shows a similar lack of correlation between gel time and age of 30-second resins, and also between the resins and their original batch tests. Thus, it can be concluded that resin gel time is an ineffective method of detecting resin quality.

Figure 34  Comparison of gel times for 15-second resin
4.5 Effect of under/over spinning

15-second resin is used in spin-to-stall systems where the bolt is spun to mix the resin, and spinning continues until the gelling resin increases the resistance. This results in breakout of a torque nut. The nut runs up the thread and is tightened against the bolt being installed. Although the gelling time of resin varies according to Figure 36 (taken from SIM 020205 report), it is not significantly important in the spin-to-stall system; it only affects the time to complete the installation. It is, however, one of the most important considerations in spin-and-hold systems using 30-second resin. While under-mixing may not allow the resin to set before torque is applied, over-mixing may destroy the resin-bolt and/or resin-rock contact resulting in poor support performance. In order to determine the effect of this phenomenon, a series of in-situ short encapsulated pull tests were conducted.
Over 30 in situ short encapsulated pull tests were conducted using Minova 15-second and 30-second resins. While 15-second resin was tested in a sandstone roof, 30-second resin was tested in a coal roof. The results are therefore not directly comparable. Each set of tests were conducted under near-identical conditions for each set of tests. The spinning speed of the roofbolter that installed the 15-second resins was 493 rpm, and the spinning speed of the bolter which installed the 30-second resins was 131 rpm.

Table 7 shows the grip factor results obtained from the tests on 15-second resin. As can be seen, the difference between the grip factor for the slowest spinning time, and that of the resin which is spun until it stalls was only 7 per cent. This figure also indicates that under-spinning of 15-second resin is not significant.

Minova (SA) recommends a 10-second spinning time for their 30-second resin, which is the bottom limit of spinning speed against gelling time, as shown in Figure 36. Table 8 shows the results obtained from the tests on 30-second resin. This table indicates that the difference between 10-second spinning (recommended) and over-spinning (15 and 20-second) is approximately 25 per cent. This shows that greater spinning times may not affect the support performance significantly with slow speed machines. However, it can
also be concluded from Figure 36 and Table 8 that the spinning time of a 30-second resin should never be more than 20 seconds, even with very low speed roofbolters (100 rpm).

**Table 7**  
*Effect of spinning time on support performance, 15-second resin*

<table>
<thead>
<tr>
<th>Spin time (second)</th>
<th>Grip Factor (kN/mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>5</td>
<td>0.56</td>
</tr>
<tr>
<td>10</td>
<td>0.60</td>
</tr>
<tr>
<td>Till stall</td>
<td>0.60</td>
</tr>
</tbody>
</table>

From the above, it is concluded that the lines shown in Figure 36 is the maximum spinning times of 30-second and 15-second resins for various spinning speeds. It is therefore recommended that resin should never be spun for longer than the values presented in Figure 36 for various speeds to avoid bond failures.

**Table 8**  
*Effect of spinning time on support performance, 30-second resin*

<table>
<thead>
<tr>
<th>Spin time (second)</th>
<th>Grip Factor (kN/mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>10 (recommended)</td>
<td>0.44</td>
</tr>
<tr>
<td>15</td>
<td>0.35</td>
</tr>
<tr>
<td>20</td>
<td>0.33</td>
</tr>
</tbody>
</table>
5.0 Testing procedures to achieve maximum support performance

There are a number of testing procedures used throughout the industry in order to determine support performance in a bolting system. Chapter 3 of SIMRAC project SIM 020205 deals with testing procedures and covers in detail procedures such as short encapsulation pull testing, laboratory short encapsulation pull testing, double embedment tensile tests and push tests. However, these tests are expensive and time consuming, therefore a simplified short encapsulated pull (SEPT) testing procedure is suggested in this chapter, which can be used for routine testing to determine the performance of roofbolting systems in collieries.

SIM 020205 (Chapter 4) also deals with testing procedures for determining the optimum parameters for roofbolters to install a support system to provide maximum performance. These tests are very simple and therefore do not require any modifications.

The resin testing facilities at Minova SA are detailed in SIM 020205. The gel tester is used to determine the quality of resin batches, and ensure that quality assurance procedures are met. Anglo Coal’s testing facilities are shown in Figure 37. These facilities were used during the project to develop a resin testing procedure. The tests conducted at these facilities indicated that monitoring of torque can give an indication of the quality of resin that will be used underground.
Figure 37  Anglo Coal's testing rig
5.1 Simplified SEPT for routine testing

Laboratory testing is usually conducted to evaluate the quality and performance of new support elements. Two types of laboratory testing methods have mainly been used, short encapsulated pull and push tests. Significant effort went into laboratory testing to simulate the underground environment. The variation in the results of laboratory tests, however, led the researchers to use more controlled testing procedures. Rock specimens with known properties were initially used to test the bolt, resin and the contact conditions, to carry out comparative assessment. However, relatively strong rocks, mainly sandstone, were used in these tests, which is not always the case in an underground environment. In addition, the difficulty in finding similar rock types for testing, forced the laboratory tests to be conducted in synthetic rocks, such as concrete.

Threaded steel pipes were also used in laboratory tests. However, the wall of the hole in which the bolt resides, is extremely stiff resulting in a high level of bond between the pipe and the grout. Since bond stress is a function of applied load and of the inverse of the area of the periphery of the bond, peripheral stresses are likely to be higher at the periphery of the bolt than at the wall of the hole – due mainly to the larger surface area of the hole wall. The combination of the stiff wall and lower bond stress implies that failure will normally occur at the bolt/grout interface which makes the test useful for the comparison of resin shear strength, but takes no account of rock quality, the results of stresses on the rock or the influence of hole geometry and surface nature. It is therefore suggested that the performance and quality control tests should be conducted underground in the environment where the roof bolts will be used.

This section provides guidance on a reliable and accurate simplified testing procedure for determining the capacity properties of roofbolts. The results from the suggested testing procedure can be used for routine quality control.

The details of the required testing equipment can be found in the final report of SIM 020205.
5.1.1 Measurements required

Since these tests will be conducted once the characteristics of the roofbolting system have been established, taking measurements from the bolt, resin capsule and the hole diameter is not required.

Bolts need to be cleaned so that they are free from dirt, loose rust, paint, or other surface contaminants.

The test bolt is marked off 250 mm from the end, and insulation tape is double wound around the next ± 150 mm as shown in Figure 38. Since detailed measurements are not taken from the bolt, resin and hole, this process will ensure the accuracy of the bond length of 250 mm. Any excess resin will flow over the taped part of the bolt and will not bond properly.

Tests holes should be drilled to the required depth. Mark the drill steel to ensure the correct depth is drilled and check hole depth after drilling with the use of the test bolt.
5.1.2 Capsule preparation and measurement of embedment length

It is also suggested that no measurements and detailed calculations are required to determine the exact length of encapsulation in the hole. However, depending on the bolt diameter, the bit size and the resin capsule diameter, an initial calculation should be made on surface prior to testing. The resin must be then be cut at the required length as calculated.

The details of required resin length can be found in the final report of SIM 020205.

5.1.3 Bolt installation procedure for SEPT

The details of bolt installation procedures are presented in the final report of SIM 020205.

5.1.4 Procedure for pulling the installed roof bolts

The details of bolt pulling procedures are presented in the final report of SIM 020205.
6.0 Conclusions

It has been established that the hot rolling process of steel used in bolt manufacture is preferential for use in the coal mining industry. This is because hot rolling produces a more consistent product in terms of the bolt’s dimensions, i.e. core diameter and rib height. In underground short encapsulation pull tests, hot rolling was seen to give better performance in terms of grip factor and stiffness when compared to bolts manufactured using the cold rolled process.

A series of test installations carried out in Perspex tubes allowed observations to be made on the quality of resin mixing when using differing installation methods. Further observations found that “finger gloving”, where the plastic cartridge of the resin capsule wraps around the installation and prevents bonding to the rock, occurred, to some extent, in almost all installations. It was found that more “finger gloving” was likely to occur if the bolt was pushed through the resin capsule before spinning took place. Whilst underground SEPTs identified a slight difference in the performance of bolts installed in this method, the difference was not great enough to be alarming and still comfortably passed recommended support requirements. It can be concluded from this that “finger gloving” is present in most installations but has little effect on the performance of the system.

Laboratory shear tests performed on full column resin roofbolts indicated that the shear strength of roofbolts is approximately 89 per cent of the ultimate tensile strength of the bolt.

SIM 020205 identified roofbolt installation as an area which must be investigated. Four different types of installation were identified, namely:

- Flat end bolt spun through resin;
- Flat end bolt pushed through resin, then spun;
- Angle end bolt spun through resin;
- Angle end bolt pushed through resin, then spun.

Visual observations on the quality of resin mixing in each method were carried out. It was observed that when bolts, either flat or angle end, were pushed through the resin capsule before spinning, a displacement of the catalyst took place. The catalyst is less viscous
than the resin and so when a bolt is pushed through the capsule, some separation of the materials occurs. Mixing of resin and catalyst cannot take place properly and so pushing a bolt through the resin capsule before spinning reduces the effectiveness of the support.

Underground short encapsulated pull tests were conducted to quantify the effects of the different methods. They showed that whilst differences in grip factor were minimal, large differences were found when comparing the stiffness of a system. In tests done for both 15-second and 30-second resins, grip factors for an angled bolt, pushed through the resin before spinning, were the poorest for both resin types. The other three installation methods performed identically well. In terms of stiffness, the flat end bolts outperformed the angle end bolts, with a flat end bolt spun through the resin capsule giving the best performance. It is therefore concluded that the best installation method is to use flat end bolts spun through the resin to achieve a stiffer roof support system.

Pull tests were also conducted on resins of various ages to determine the effect of resin expiry date upon performance. It was established that performance of the system is reduced as the time increases past the expiry date. A resin which had expired by 6 months gave 33 per cent poorer performance than a new resin.

In order to determine a resin testing procedure, a series of tests were conducted using the testing facilities at Anglo Coal Rock Engineering Laboratory. Resins of different ages were tested. The results indicated that the older the resin, the lower the torque achieved. This indicates that a torque test could be a quick and easy method of determining expired resin.

Tests were also conducted to determine whether resin gel time could be used to determine expiry of a resin but the results proved inconclusive.

The effects of over or under spinning of resin were observed and the effects quantified. It was established that under spinning of a 15-second spin to stall resin still provided results within the acceptable limits of performance. For a 30-second resin, over spinning resulted in reduced performance and it was concluded that a 30-second resin should not be spun for more than 20 seconds no matter how low the spinning speed of the bolter.
A simplified short encapsulated testing procedure is suggested, which eliminates the time consuming measurements are taken in detailed SEPT. It is suggested that the measurements taken from the bolt, resin capsule and hole diameter can be eliminated without jeopardising the quality of test results.
7.0 References

