# Chapter 6.0

# Evaluation of roof bolting systems in South Africa

## 6.1 Introduction

One other important consideration in determining the performance of a support system as a whole is the bolting components that are used in the design. Therefore, an in-depth study into the bolting elements that are currently being used n South African collieries was conducted.

There are five important components of a bolting system, which determine the quality of an installed support. These are:

- Machinery; equipment;
- Bolt;
- Resin;
- Hole;
- Rock type

These five components are of equal importance, as failure of any of these will result in an inadequate support system. Therefore, as part of this task, all important parameters of these five components have been investigated. The important parameters of the five components are given below:

**Machinery and equipment**

- Torque;
- Thrust;
- Effect of different drill bits on the support performance; and
- Free rotation, spinning and drilling speeds.

**Bolt and components (thread, nut and washer)**

- Bolt profile;
- Effect of preload on bolt and components;
- Variation of diameter and rib heights; and
- Deformability.

**Resin**

- Set and spin times;
- Effect of roofbolter spinning speed;
- Resin type; and
- Effect of plastic encapsulation.

**Bolt hole**

- Effect of wet and dry drilling on system performance and hole profile;
- Hole profile as a function of the bit characteristics;
- Size of annulus between bolt and hole;
- Effect of drilling speed on hole profile.

**Rock type**

The geology is also a very important external component of the support system. An understanding of the interaction between the rock and the bolting system is crucial; therefore, to achieving the most appropriate support system for different geological environments.

## 6.2 Specifications for roofbolters

### 6.2.1 Introduction

The quality of installation of a support system is directly related to the performance of the equipment that is used to install the bolts. The performance of bolting equipment was therefore investigated as part of this study in order that the relative importance of the various machine parameters could be ascertained, as well as the range in values of these parameters as provided by the equipment used in South African collieries.

The following parameters were assessed in determining the performances of bolting equipment:

- Drilling speed: determines the hole profile;
- Spinning speed: determine the resin mixing characteristics and hole profile;
- Torque: determines the tension on the bolt and the capability of installing shear-pin bolts;
- Thrust: determines the hole profile and pushing the bolt through the resin; and

These parameters were then measured against roof bolt performance in various rock types. It should be noted that currently in South Africa, there are no standards for these parameters in collieries, except the torque, which should be approximately 240 Nm (Torqueleader, 2005) in order to generate approximately 50 kN (5 tonnes) for tensioning by roofbolters.

A total of 143 roofbolters, which were operational during the evaluation, were tested from 27 different collieries, ranging from Tshikondeni in the north to Zululand Anthracite Colliery (ZAC) in the east. This provided a comprehensive database of roofbolter information. Tests were done on a variety of machines from different manufacturers, including Rham, Fletcher, Voest Alpine, License, Klockner, Biz Africa, along with custom-designed bolters manufactured by particular mines. Results from all of these machines varied widely, even to the extent of differing from boom to boom on twin boom machines.

### 6.2.2 Testing procedure

During this investigation, the testing procedure for each machine followed a set pattern, which was developed to be as quick and easy as possible, in this way minimizing any possible downtime to production machines. For each machine, the torque setting at which the machine spins the bolt was measured, to ensure that the machine was capable of breaking out either the crimp or shear pin of the bolt, if such a future was present.

Following this, a hole was drilled and the speed of drilling was measured in revolutions per minute using a laser digital tachometer. This device quickly and easily measures the speed by simply attaching a reflective strip to the drill chuck or drill steel, and shining the laser onto the strip while the drilling is in progress.

Once the hole was drilled, the depth was measured and a borehole micrometer was inserted to measure the hole diameter at intervals along the length of the hole. This gives an indication of the hole profile as drilled by the particular bit type at a specific rotation speed. Measurements were taken from two to three holes per roofbolter.

A bolt is then inserted into the chuck and a load cell fitted over the bolt. The bolt is pushed into the hole, without inserting resin, and pushed against the roof with the maximum force possible to establish the thrust that the roofbolter is capable of exerting against the bolt, which is important when full-column roof bolts are being installed and a bolt is being pushed through several resin capsules.

The bolt was then installed with resin and a speed measurement is taken while the bolt was being spun through the resin. This measurement shows the speed at which the resin is being mixed.

The form, presented in Figure 6-1 was used to record measurements during the testing. Other measurements taken were standard lengths and diameters, the bit type and diameter, drill steel length and diameter, type of bolt, bolt length and diameter. The type of support, be it mechanical point anchor, resin point anchor or full-column resin was noted and resin type, capsule length and diameter recorded.

Finally, drilling type (wet or dry) was noted, as this may have considerable impact on the hole profile in different rock types. Where possible, a borehole log of the area in which tests were conducted was collected in order to take into account the influence of the immediate roof in which installation is taking place.

<table>
<tr><td><b>Date</b></td><td colspan="2">29/11/2002</td></tr>
<tr><td><b>Mine</b></td><td colspan="2">Goedehoop - Hope Shaft</td></tr>
<tr><td><b>Section</b></td><td colspan="2">9/10</td></tr>
<tr><td><b>Mining Method</b></td><td colspan="2">Bord and Pillar - CM</td></tr>
<tr><td><b>Production Rate</b></td><td colspan="2">+/- 1000 tonnes/shift</td></tr>
<tr><td><b>Type of Roofbolter</b></td><td colspan="2">Fletcher MDDR - 17 SN - 2001026</td></tr>
<tr><td><b>Date of Purchase</b></td><td colspan="2">14/06/2001</td></tr>
<tr><td><b>Cycle Time (Bolts per hour/shift)</b></td><td colspan="2">LHS - 60 seconds / 1.5m RHS - 77 seconds / 1.5m</td></tr>
<tr><td><b>Bit Type</b></td><td colspan="2">Spade</td></tr>
<tr><td><b>Bit Diameter (mm)</b></td><td colspan="2">25.3mm</td></tr>
<tr><td><b>Drill Steel Diameter (mm)</b></td><td colspan="2">22.3mm - Flat 24.1mm - Hex</td></tr>
<tr><td><b>Drill Steel Length (m)</b></td><td colspan="2">1.44m</td></tr>
<tr><td><b>Type of Support</b></td><td colspan="2">f/c</td></tr>
<tr><td><b>Type of Resin</b></td><td colspan="2">Fasloc 'A' spin to stall</td></tr>
<tr><td><b>Capsule Diameter (mm)</b></td><td colspan="2">21.4mm</td></tr>
<tr><td><b>Capsule Length (mm)</b></td><td colspan="2">495mm</td></tr>
<tr><td><b>Type of Bolt</b></td><td colspan="2">Rebar, shear pin</td></tr>
<tr><td><b>Bolt Diameter (mm)</b></td><td colspan="2">Core - 20.2mm Rib - 21.3mm Parallel - 20.4mm</td></tr>
<tr><td><b>Bolt Length (m)</b></td><td colspan="2">1.5m</td></tr>
<tr><td><b>Bolt Consumption</b></td><td colspan="2">+/- 80 / shift</td></tr>
<tr><td><b>Washer Type</b></td><td colspan="2">Dome - Dog Eared</td></tr>
<tr><td><b>Washer Dimensions (mm)</b></td><td colspan="2">125 x 125 x 5.1mm</td></tr>
<tr><td><b>Type of Pin/Nut</b></td><td colspan="2">Shear pin</td></tr>
<tr><td><b>Dry/Wet Drilling?</b></td><td colspan="2">Dry</td></tr>
<tr><td></td><td><b>Left Boom</b></td><td><b>Right Boom</b></td></tr>
<tr><td><b>Free Rotation Speed (rpm)</b></td><td>614</td><td>622</td></tr>
<tr><td><b>Drill Speed (rpm)</b></td><td>605</td><td>572</td></tr>
<tr><td><b>Resin Spinning Speed (rpm)</b></td><td>604</td><td>592</td></tr>
<tr><td><b>Torque (Nm)</b></td><td>180</td><td>260</td></tr>
<tr><td><b>Thrust (kN)</b></td><td>780</td><td>500</td></tr>
<tr><td><b>Hole Length (m)</b></td><td>1.44m</td><td>1.45m</td></tr>
<tr><td><b>Borehole Log</b></td><td></td><td>/</td></tr>
</table>

| **Hole Profile** | | |
|---|---|---|
| **1** | **2** | **3** |
| | | |
| | | |
| | | |
| | | |
| | | |
| **4** | **5** | **6** |
| | | |
| | | |
| | | |
| | | |
| | | |

1. The first hole profile reading should be taken +/- 2 inches from the back of the hole.
2. Bolt should be pushed through the resin before measuring spinning speed.
3. Three speeds are to be measured. Free rotation, drilling, and resin spinning speeds.
4. Stop measuring the drilling speed before the hole is finished.
5. Bolt diameter measured across core, across ribs and across parallel rib.

***Figure 6-1 Form used for recording data from equipment tests***

### 6.2.3 Results

#### 6.2.3.1 Rotation speed during drilling

The results of rotation speed during drilling are presented in Figure 6-2, Figure 6-3, Figure 6-4, and Figure 6-5. These figures highlight that there is a significant variation in the drilling speeds of various bolters. As would be expected, the curve is shifted lower down the axis with the introduction of load to the system. The maximum rpm is 816, with a minimum of 148 rpm. Results for Bolter B are above the average, the largest proportion being in the 550 to 600 rpm range. Similarly, Bolter A and other bolters behave in the same way as the majority of the results falling within the 250 to 400 rpm range. The effect that rock type has on the drilling speed is discussed later in the report.

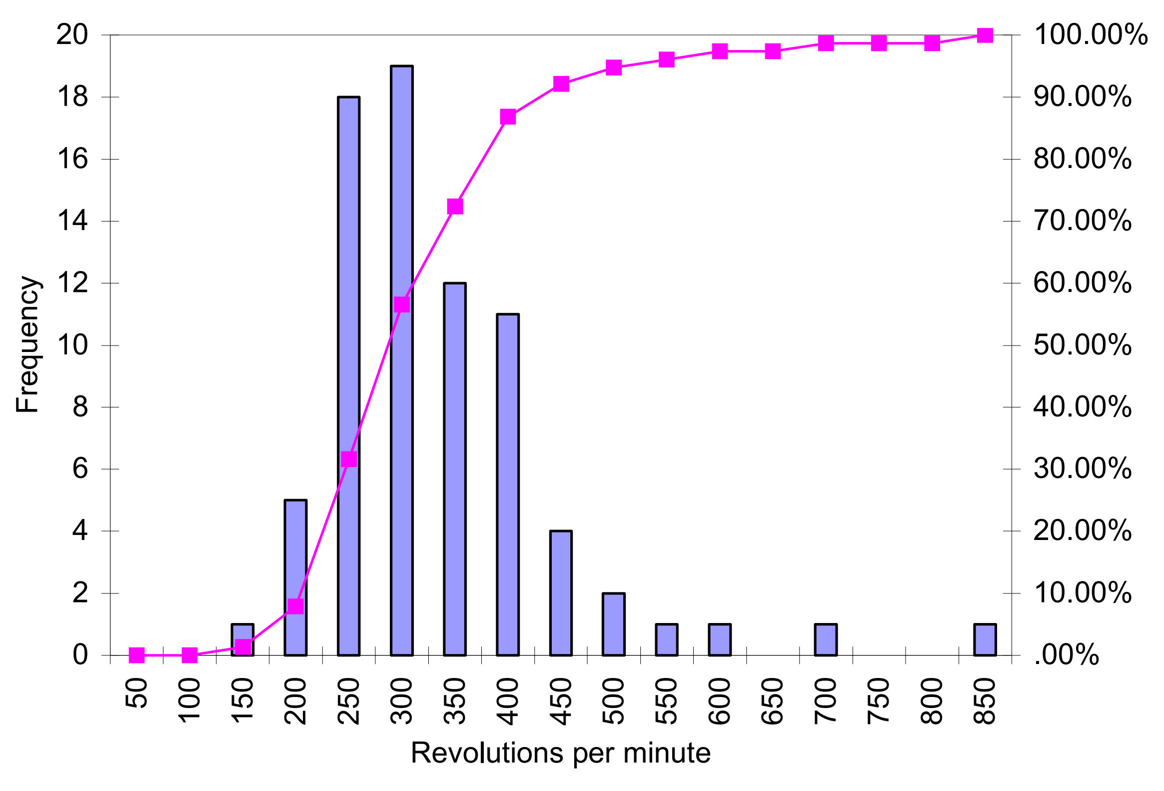


***Figure 6-2 Drilling speed - bolter A***

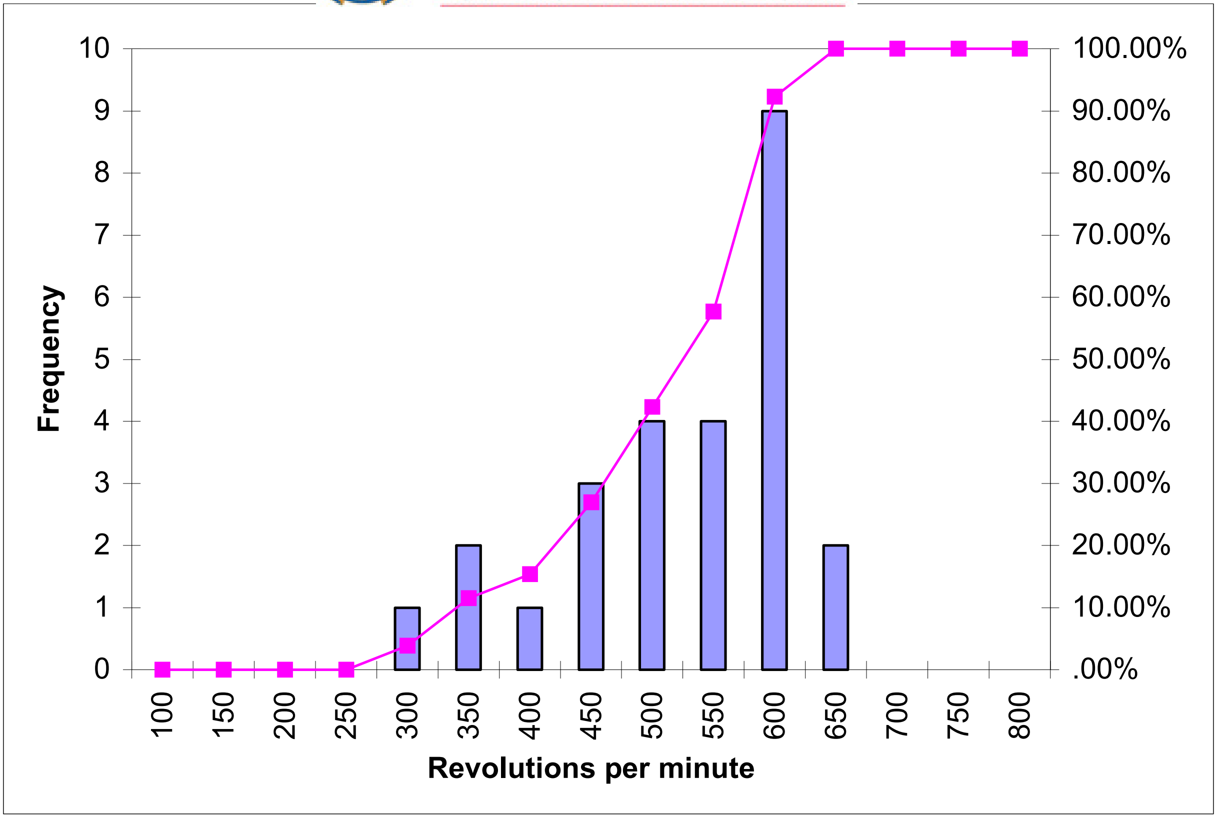


*Figure 6-3 Drilling speed - bolter B*

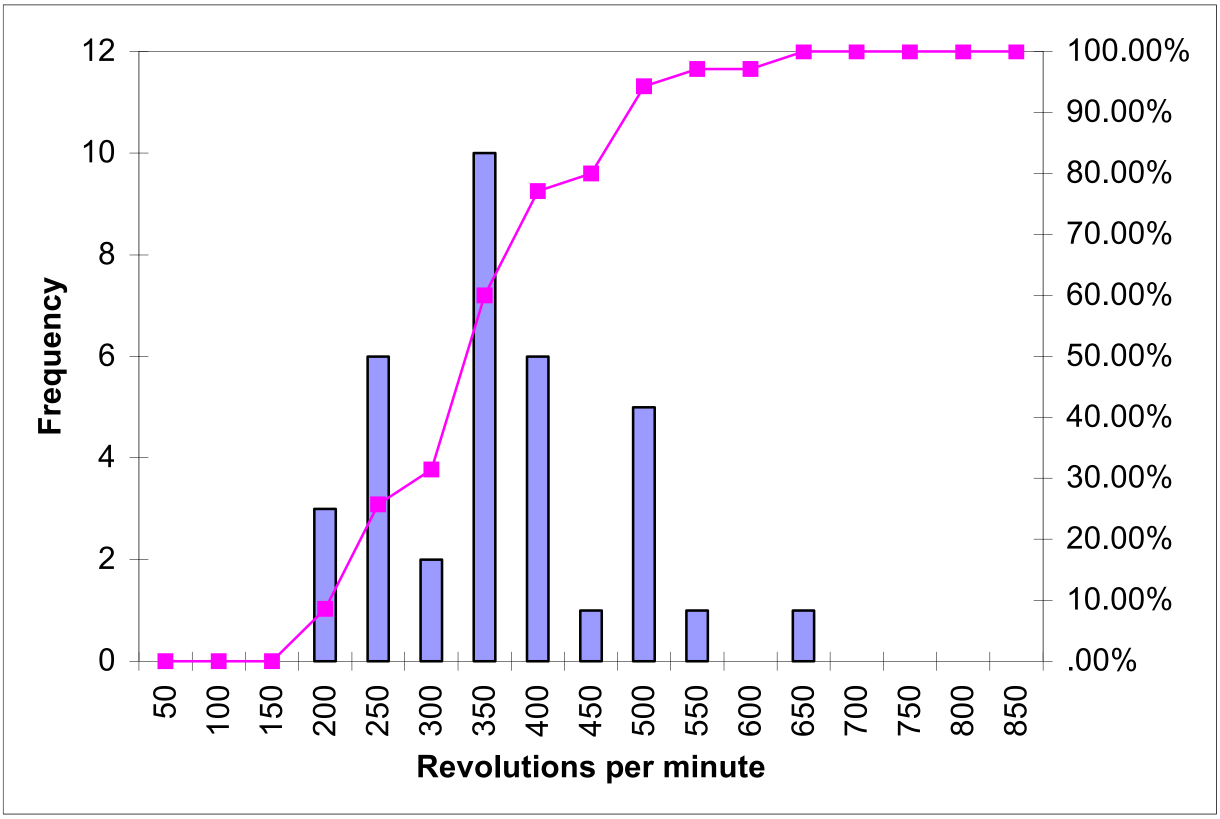


*Figure 6-4 Drilling speed - other bolters*

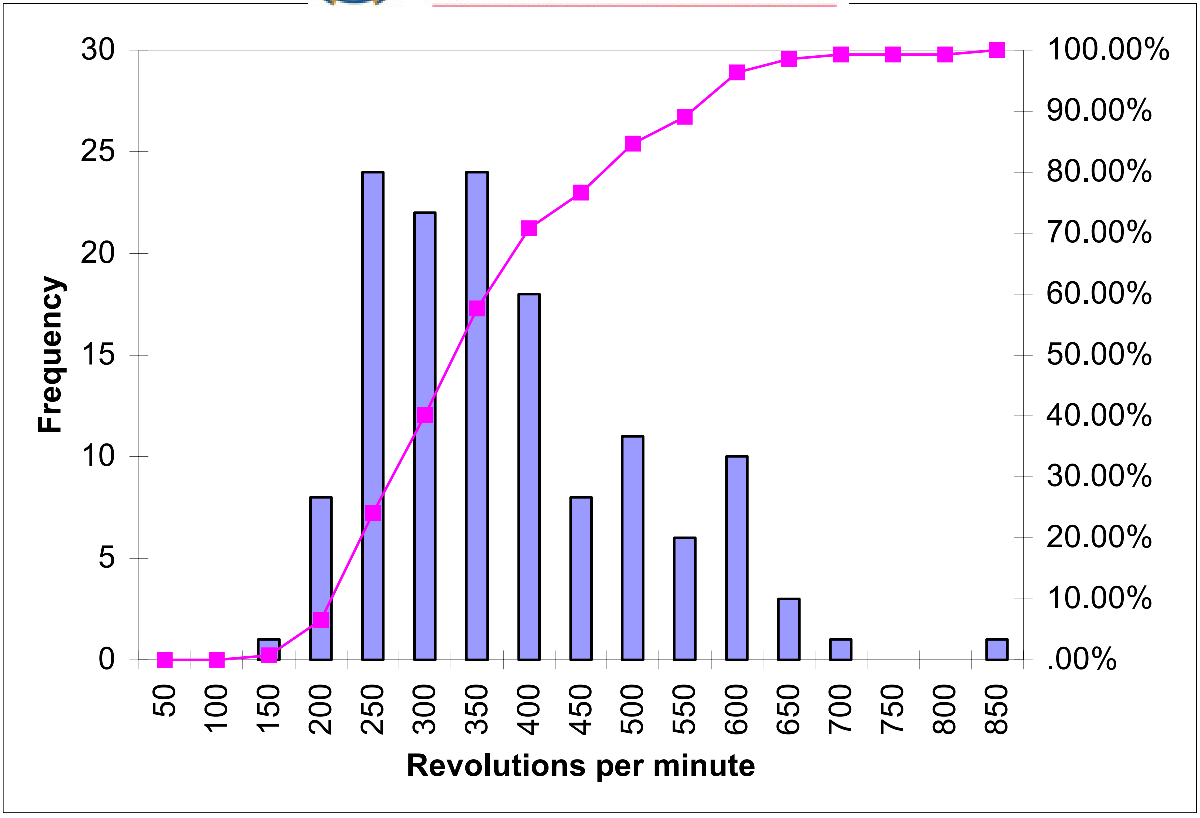


***Figure 6-5 Drilling speed - all bolters***

### 6.2.3.2 Resin spinning speed

The speeds measured while spinning resin for various types of bolters are shown in Figure 6-6, Figure 6-7, Figure 6-8, and data from all the bolters is plotted in Figure 6-9. Resin spinning speeds, generally, show much lower results than either of the other speed measurements. The resistance offered by the resin capsule in a confined space reduces the speed considerably. Resin spinning speed shows a maximum speed of 643 rpm and a minimum of 45 rpm. The distributions within the groups, however, tend to be similar to drilling speed, with the results of Bolter B being proportionately higher than those of the other two groups. Resin manufacturers recommend a spinning speed of between 400 and 500 rpm on “A” type spin-to-stall resin. Obviously, too low a spinning speed may not mix the resin correctly in the required spinning time, and result in a weak bond. It is also possible that too high a spinning speed may over-spin the resin, damaging the bond and reducing the strength. Figure 6-9 indicates that the resin spinning speeds of approximately 22 per cent of all bolters tested are within the resin manufacturers recommended range.

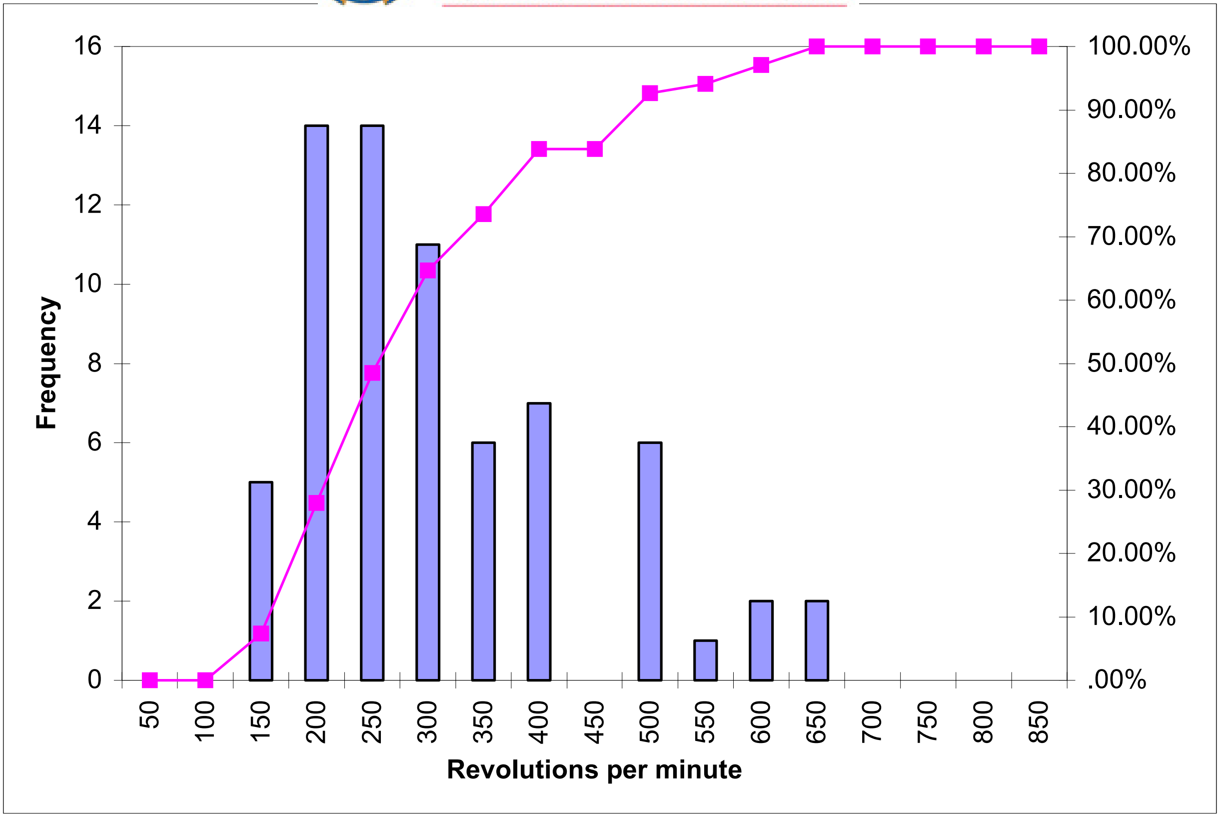


*Figure 6-6 Resin spinning speed - bolter A*

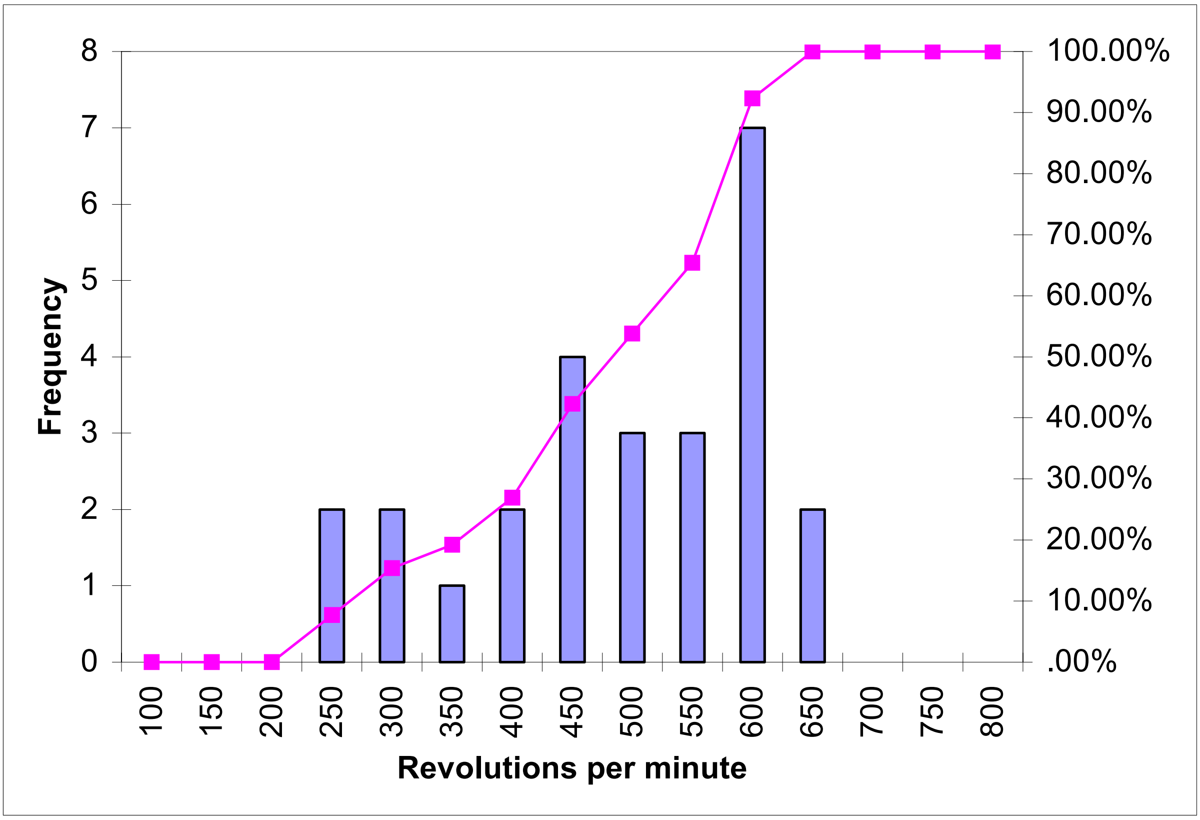


*Figure 6-7 Resin spinning speed - bolter B*

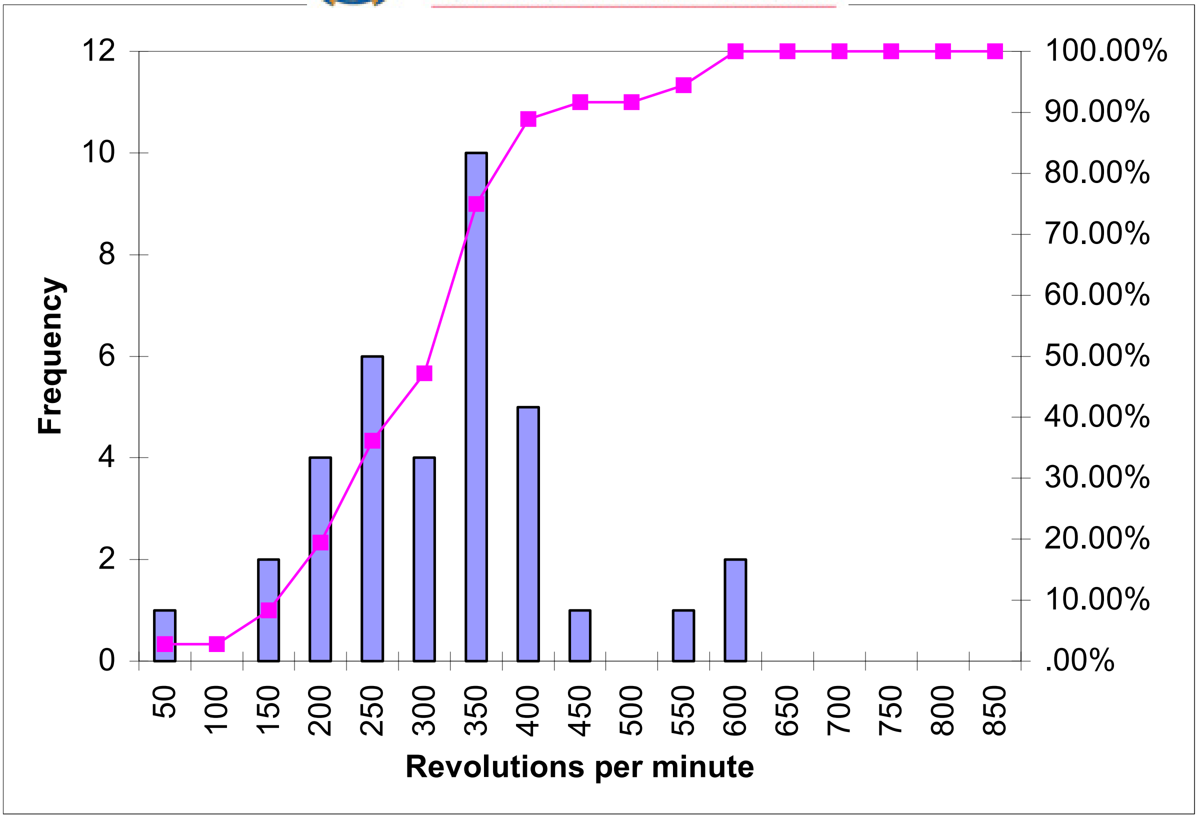


*Figure 6-8 Resin spinning speed - other bolters*

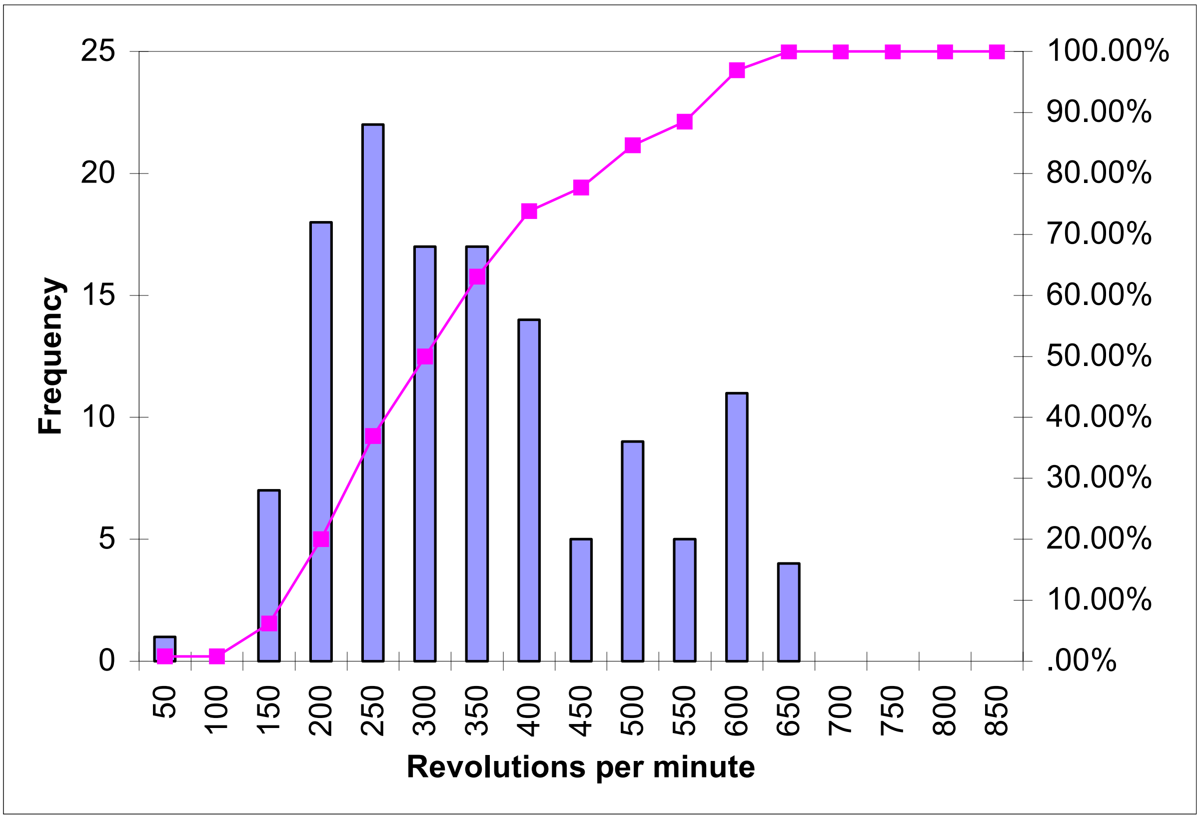


*Figure 6-9 Resin spinning speed - all bolters*

#### 6.2.3.3 Torque

Currently in South Africa, a roofbolter is expected to produce 200 Nm to 250 Nm torque at all times in order to tension the bolt to approximately 50 kN (5 tonnes).

In the drilling phase, enough torque is required to allow the bit to penetrate whatever rock type may be present in the roof and pass through harder layers with the same efficiency as through soft. When the bolt is installed, enough torque is also required to ensure a sufficient mix of resin and catalyst and also to break out the crimp or shear pin on a bolt, should one be present.

The results from the torque measurements are shown in Figure 6-10, Figure 6-11, Figure 6-12, and Figure 6-13. These figures indicate that the torque on all machines ranges from a maximum of 560 Nm to a minimum of 50 Nm. The lower value is not sufficient to break the crimp or shear pin (120 kN torque is required to break the shear pin), and this was observed to be the case on one mine. The bolter in question was tested and found to provide torque of 80 Nm. Observation of the roof bolt crew trying to install bolts made it clear that the machine was unable to break out the shear pin. The spread of torque values for all bolters show a similar distribution and variability.

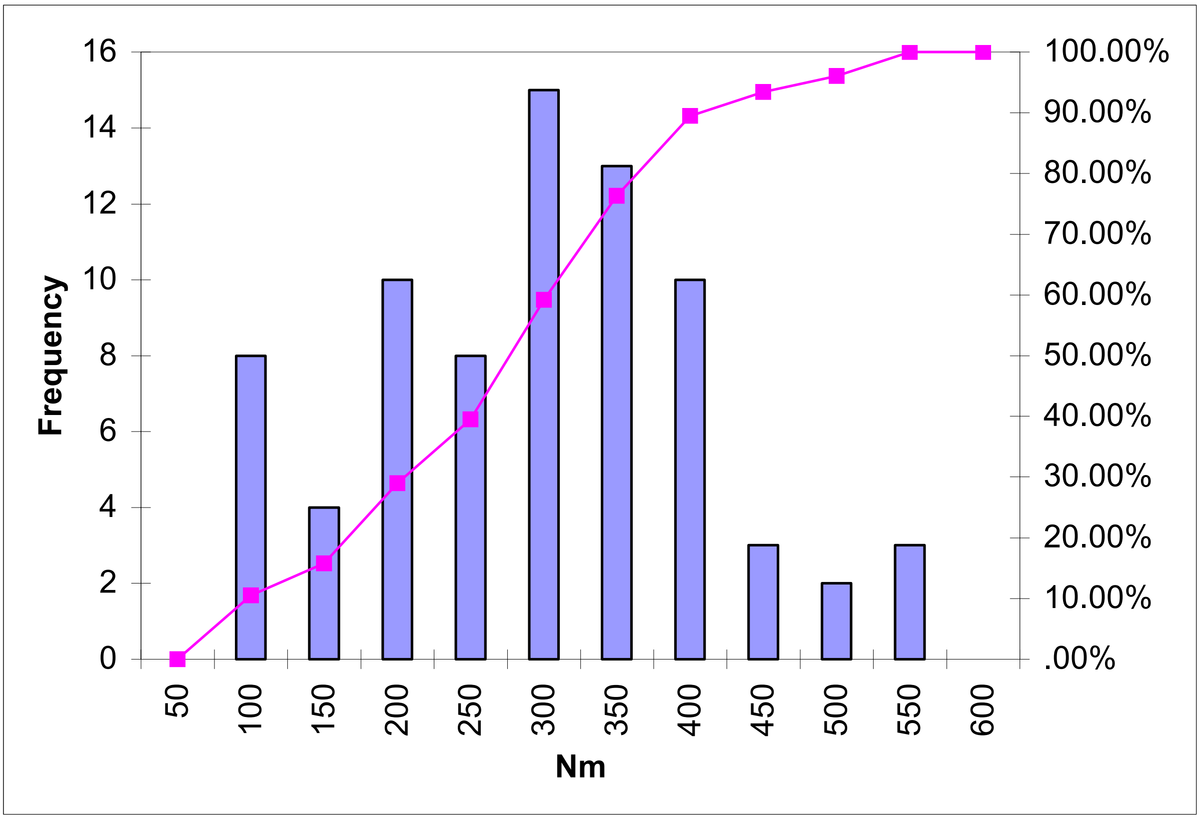


*Figure 6-10 Torque - bolter A*

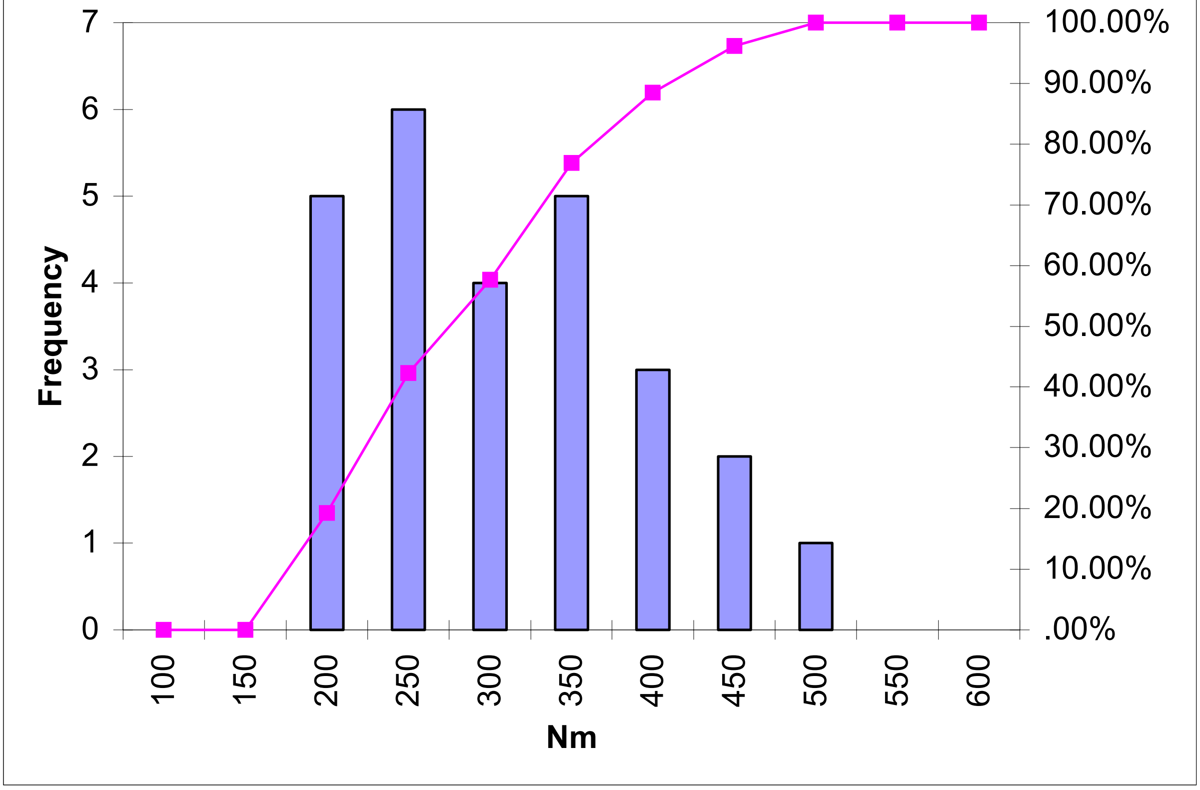


*Figure 6-11 Torque - bolter B*

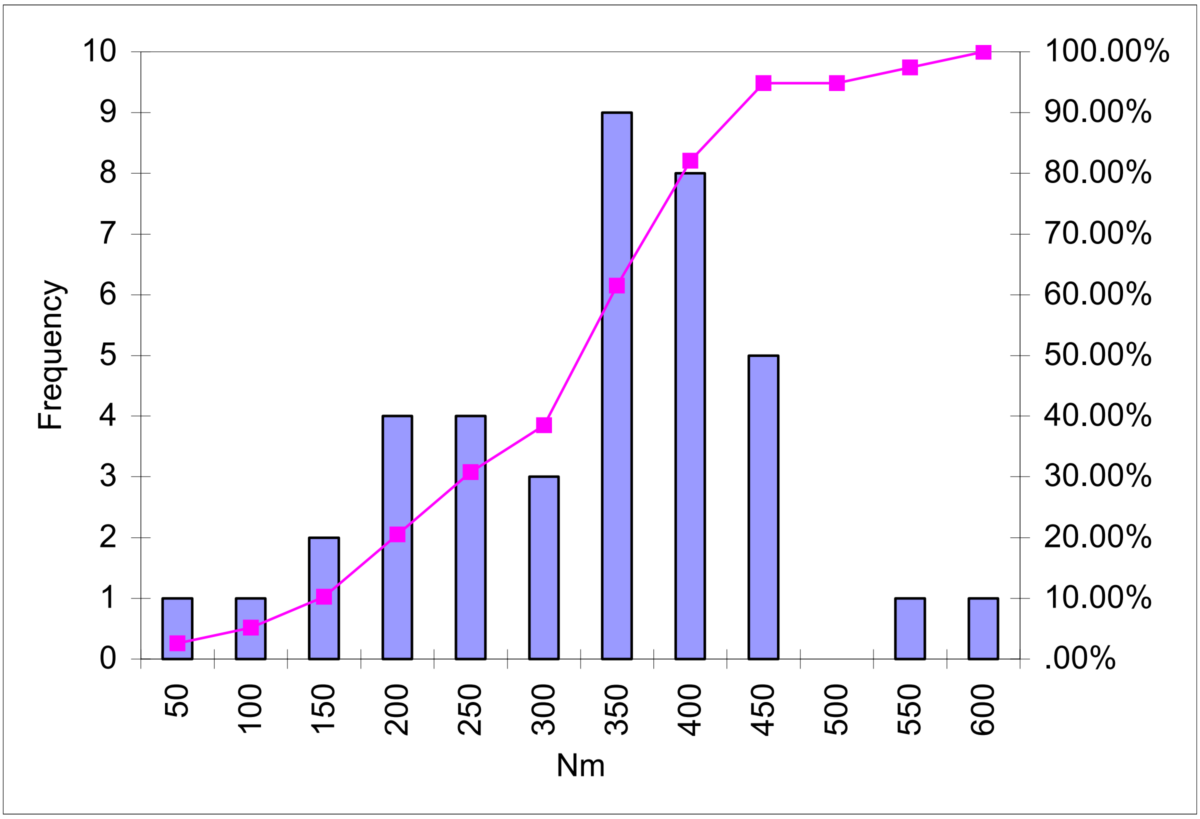


*Figure 6-12 Torque - other bolters*

Figure 6-13 indicates that only 26 per cent of all bolters had torques within the 200 Nm to 250 Nm range.

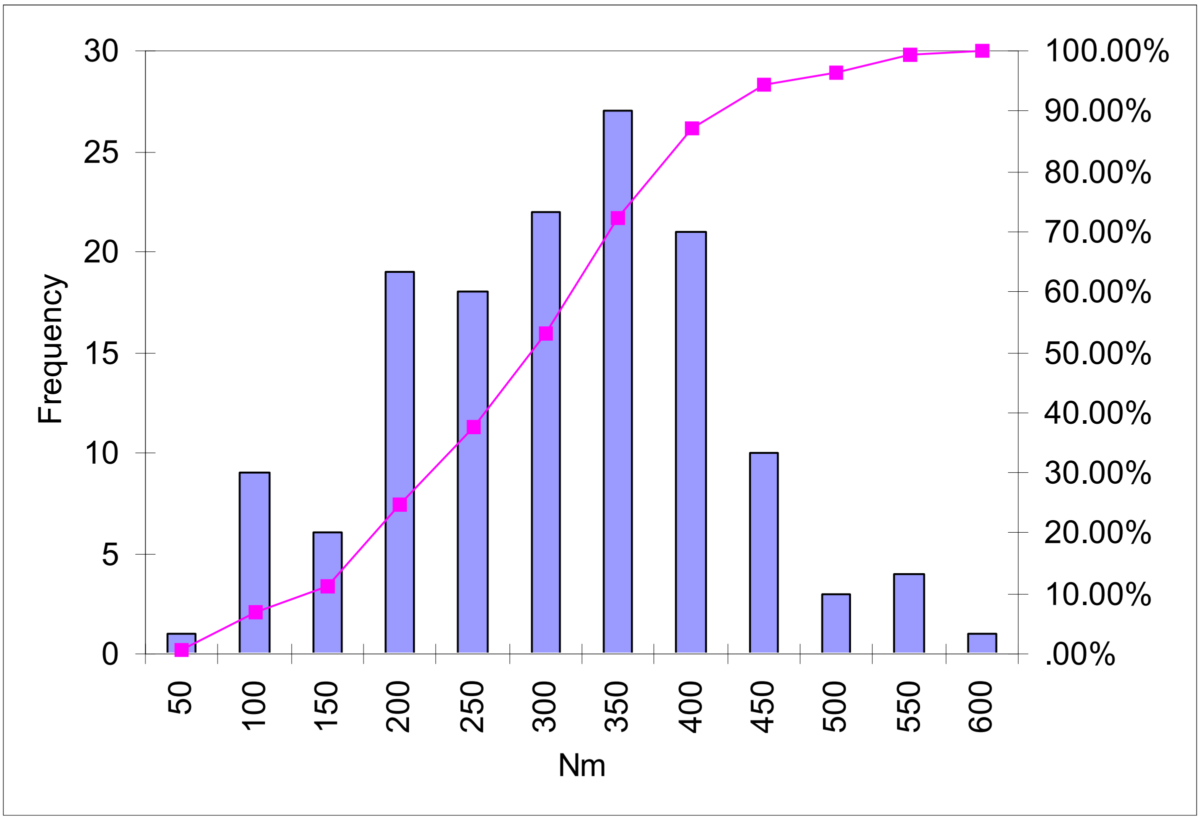


***Figure 6-13 Torque - all bolters***

### 6.2.3.4 Thrust

Thrust is the axial force exerted on the drill steel by the machine. Thrust applied while a hole is being drilled is difficult to measure. For this reason, the thrust given in this section is the maximum thrust capacity of the machine. Thrust is required in order to penetrate the roof, and also to force the bolt through a resin capsule to the back of the hole before spinning occurs. Thrusts of the roofbolters tested vary significantly, from as little as 10 kN to 32 kN, with an average of around 18 kN.

The results are presented in Figure 6-14, Figure 6-15, Figure 6-16, and Figure 6-17.

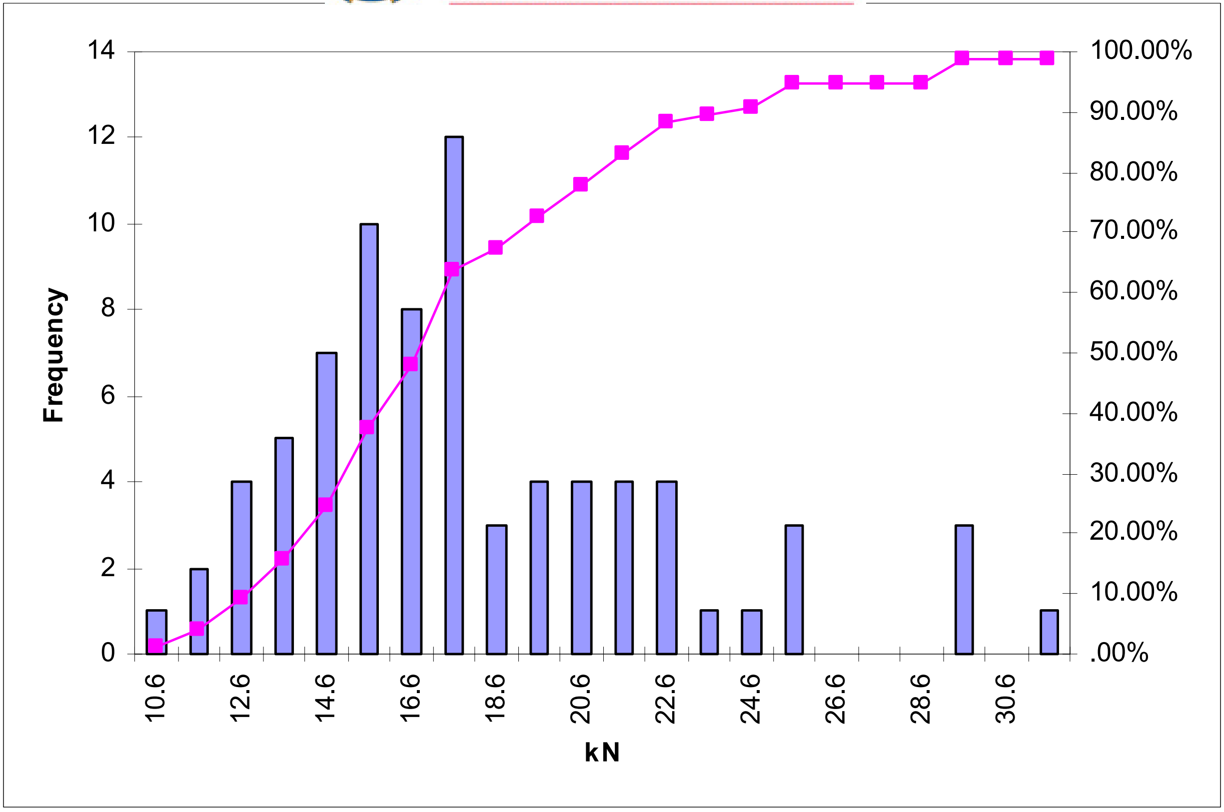


*Figure 6-14 Thrust - bolter A*

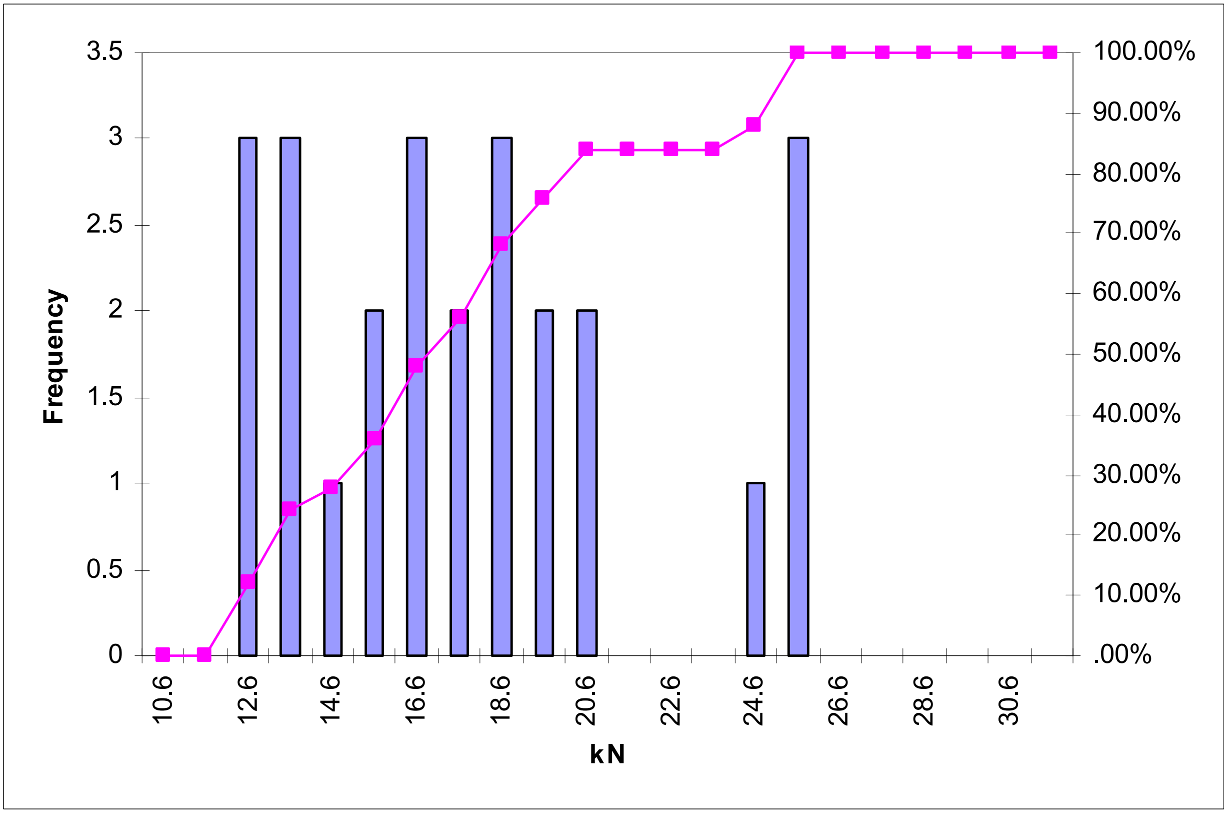


*Figure 6-15 Thrust - bolter B*

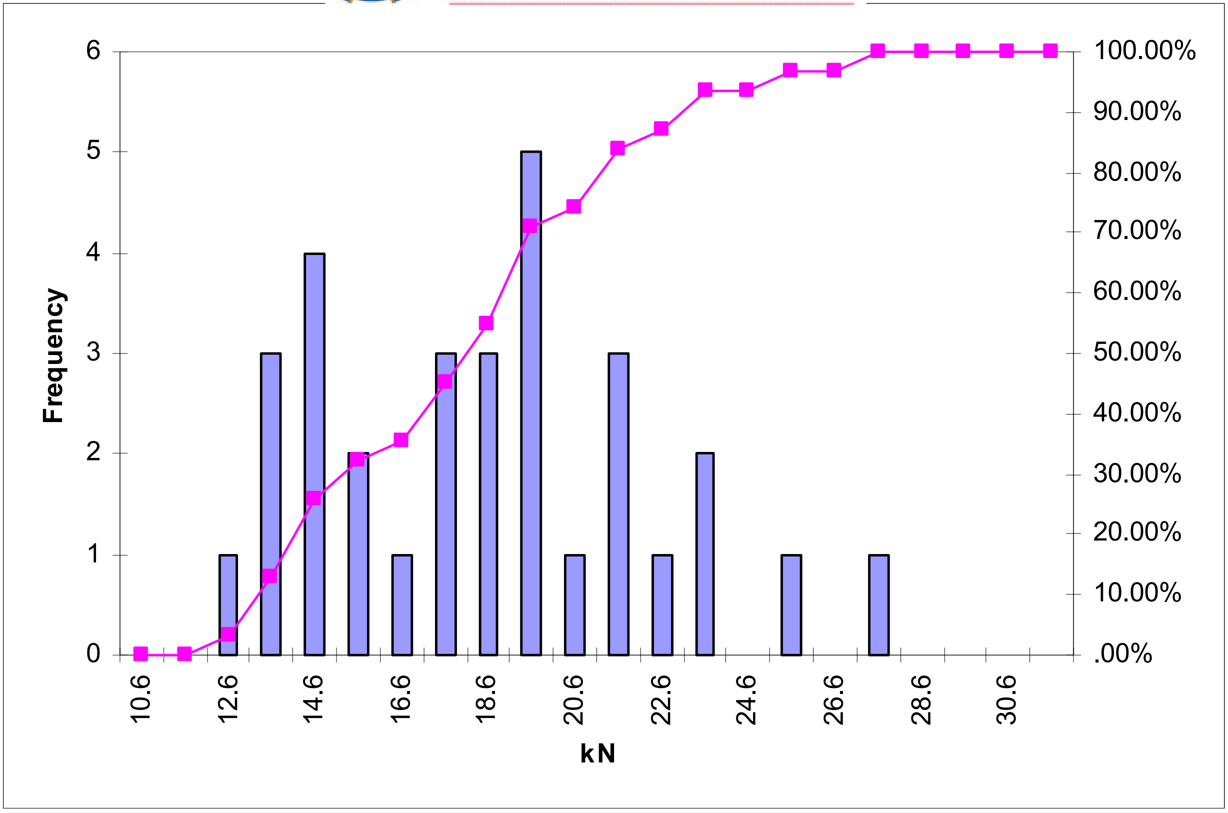


*Figure 6-16 Thrust - other bolters*

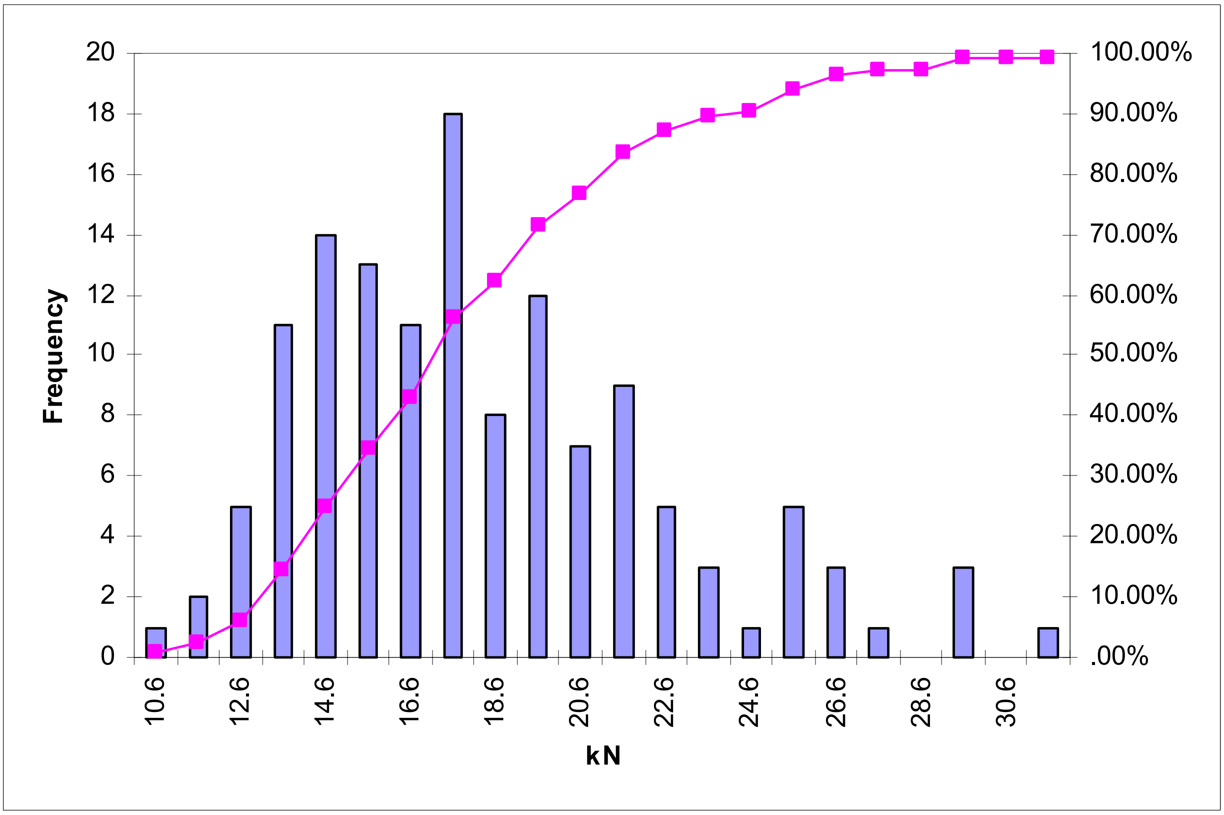


*Figure 6-17 Thrust - all bolters*

#### 6.2.3.5 Hole profile

The hole profile is also a fundamentally important parameter, as it determines the bonding quality between the resin and rock. A smooth-walled hole would exhibit lower bond strength than a hole wall that is serrated or 'rifled'.

Currently, there is no suitable tool available to determine the hole profile, apart from overcoring. However, overcoring is very expensive and cannot practically be used for a large-scale experiment applied to all available bolters in South Africa.

Therefore, the hole profile is measured by taking a number of hole diameter measurements at regular intervals along the hole. This gives an indication of the quality of hole being drilled in each particular test. A mean is calculated for the five diameter measurements, and the standard deviation determined. The standard deviation gives a description of the quality of hole drilled; the smaller the deviation, the smoother the hole. With this in mind, comparisons were made between hole quality and other measurements in an attempt to try and find links between the controllable factors and the quality of hole. The most obvious factors influencing the hole quality should be the drilling speed, torque and thrust of the bolter in a particular rock type. As can be seen from the graphs below, no correlation was however found between any one of these factors. The hole profile was then compared for wet drilling and dry drilling machines, again results indicates no apparent correlation.

As shown in Figure 6-18, the largest percentage (approximately 80 per cent) of standard deviation on all holes, drilled by all machines, in all different roof types, is less than 1.0 mm diameter over the entire hole length. Although 1.0 mm may seem insignificant, the fact remains that most 25 mm drill bits are shown to be drilling 27 to 28 mm diameter holes. This indicates that most 20 mm bolts are being installed in a hole with an annulus of up to 10 mm, when the worst case example of almost 2 mm standard deviation is taken.

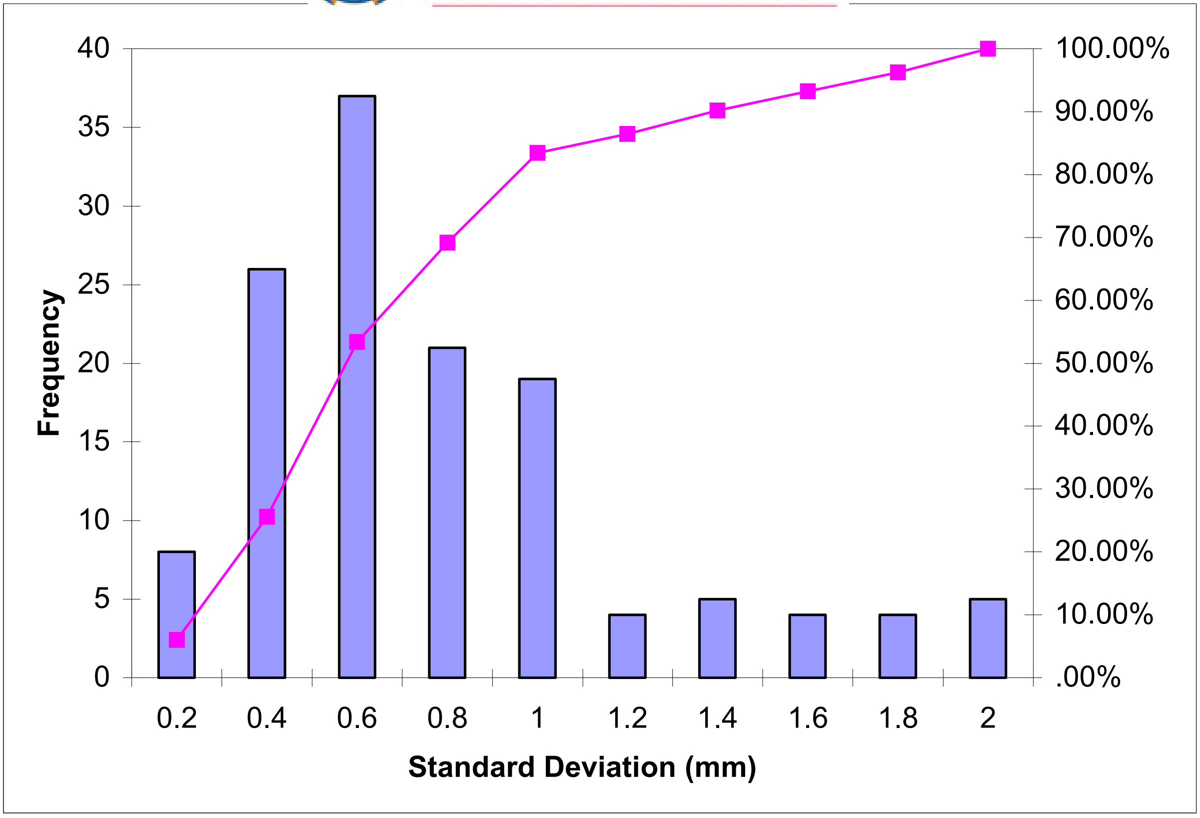


*Figure 6-18 Hole profile standard deviation frequency*

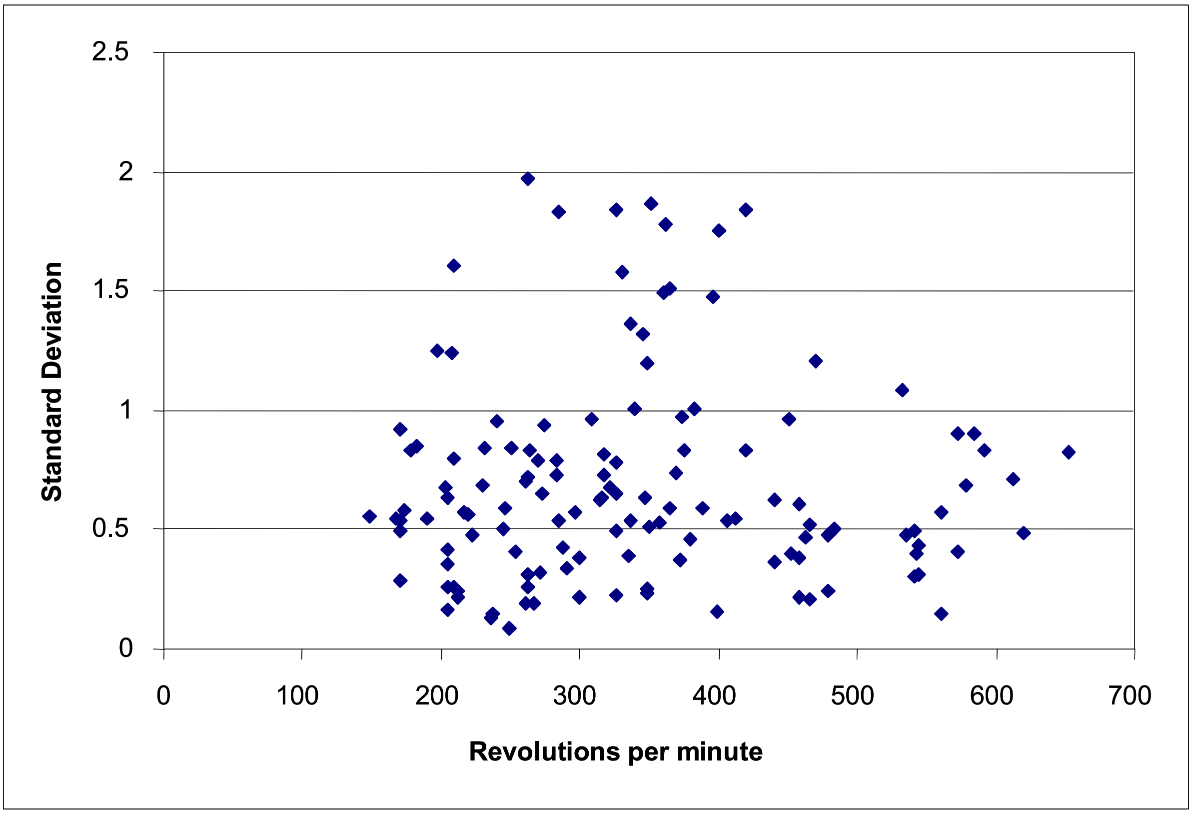


*Figure 6-19 Drilling speed against hole profile standard deviation*

One of the most obvious factors influencing the quality of the hole would be the speed at which the hole is drilled. A hole drilled at high speed would either have a very smooth profile as a result of the speed of drilling, or would produce a large diameter hole because of inadequate flushing, which is more likely at high speed. As can be seen from Figure 6-19, there is no correlation between drilling speed and hole diameter standard deviation.

Figure 6-20 shows that there is a very wide range of torque settings on roof bolting machines in South Africa, and that they do not correlate with the regularity of the hole profile.

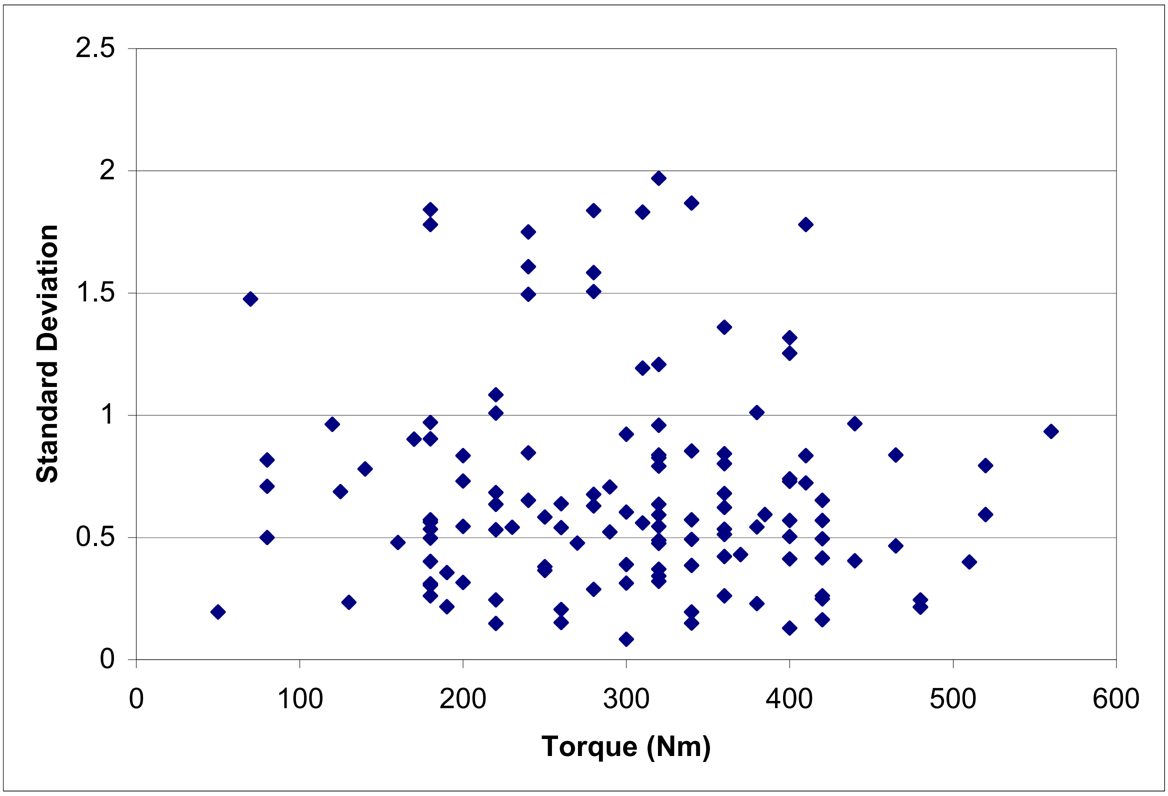


***Figure 6-20 Torque against hole profile standard deviation***

Similarly, Figure 6-21 shows no correlation between the standard deviation and thrust.

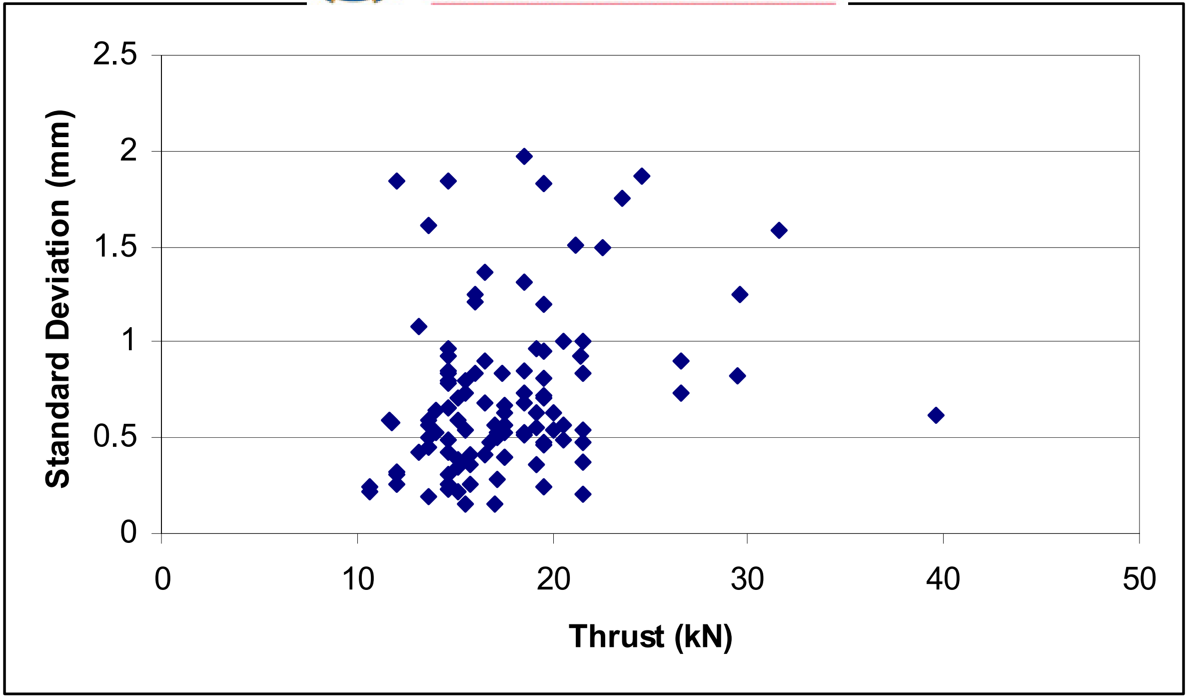


*Figure 6-21 Thrust against hole profile standard deviation*

Figure 6-22 shows the relationship between drilling speed and hole quality for wet flushing systems only. Again, no correlation is evident. A similar analysis is also conducted for dry drilling machines (Figure 6-23), again showing no obvious correlation.

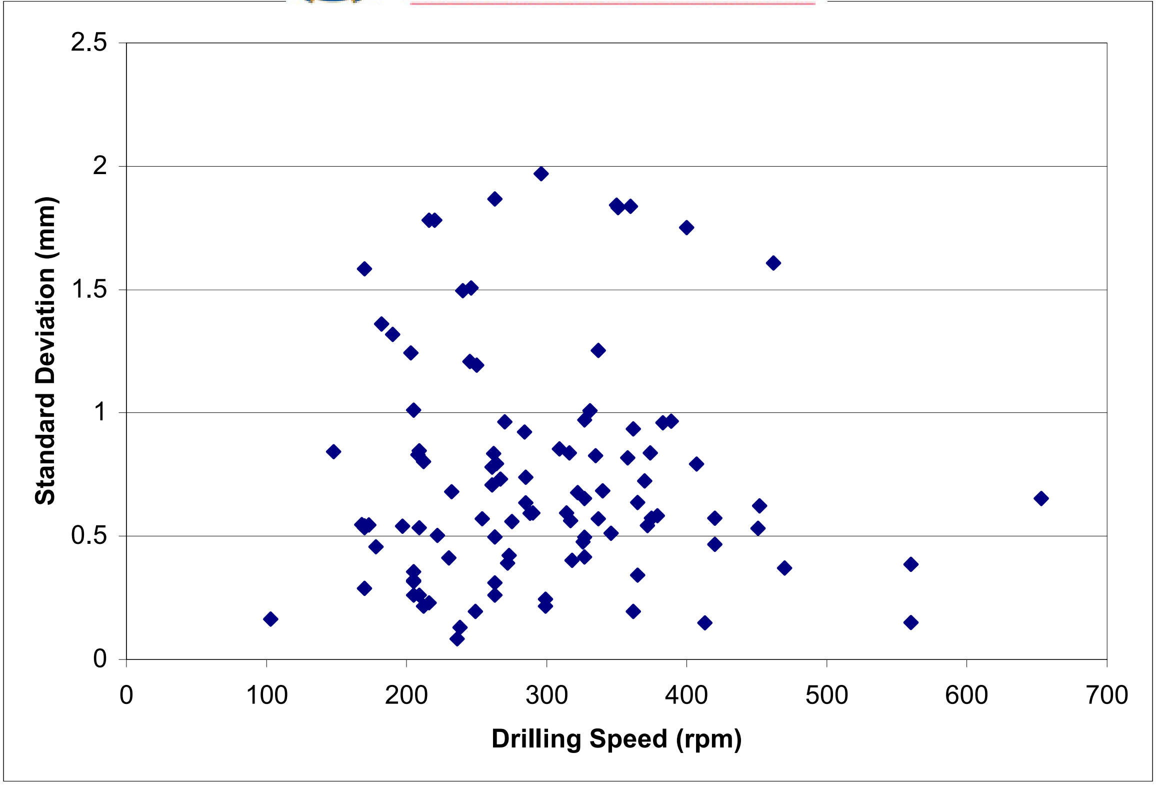


***Figure 6-22 Drilling Speed against hole profile standard deviation in machines using wet flushing system***

While the comparison between wet drilling machines and dry drilling machines must be made, Figure 6-22 and Figure 6-23 illustrate that dry drilling machines, on average, drill at higher speeds than their wet counterparts, rather than produce any discernable difference in hole quality.

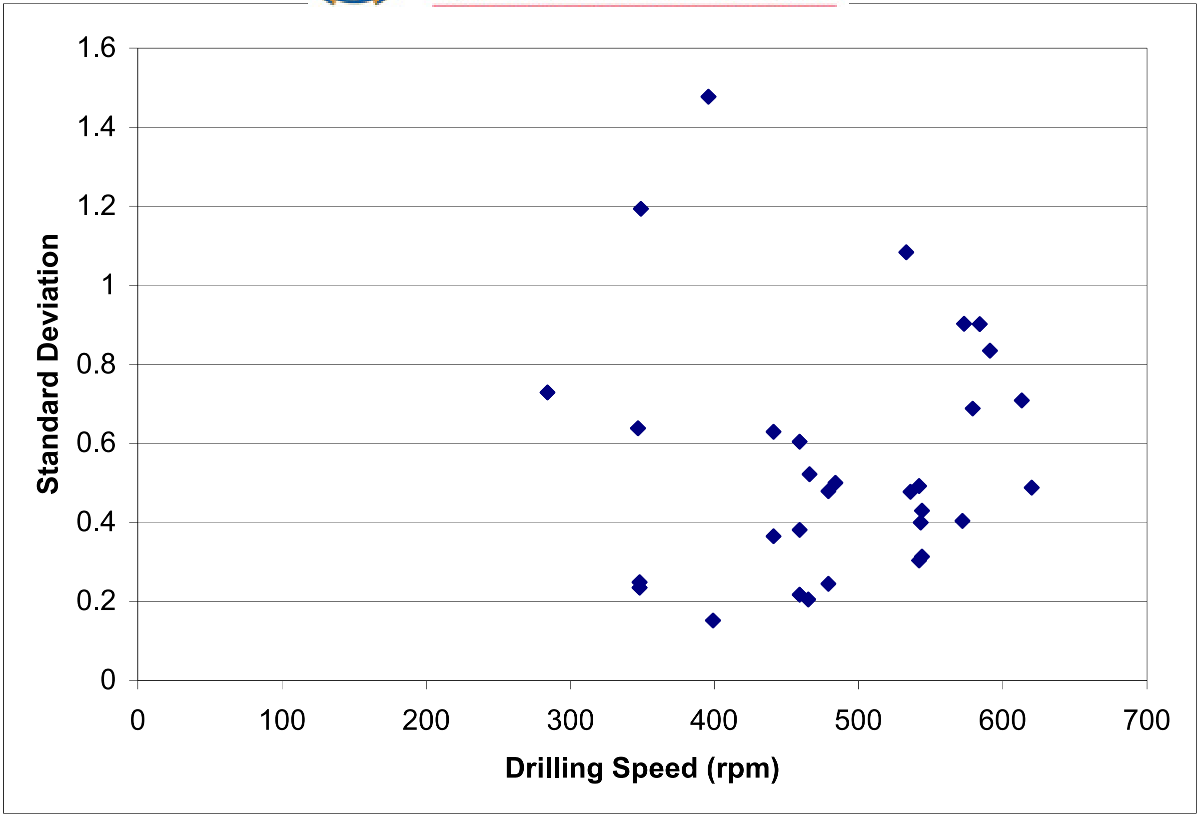


***Figure 6-23 Drilling speed against hole profile standard deviation in machines using dry flushing system***

The relationship between torque and hole quality for dry drilling machines is presented in Figure 6-24. Similarly, no correlation is evident.

The final parameter that was checked against hole profile was resin spinning speed Figure 6-25. It was also found that there is no correlation between the hole profile and resin spinning speed.

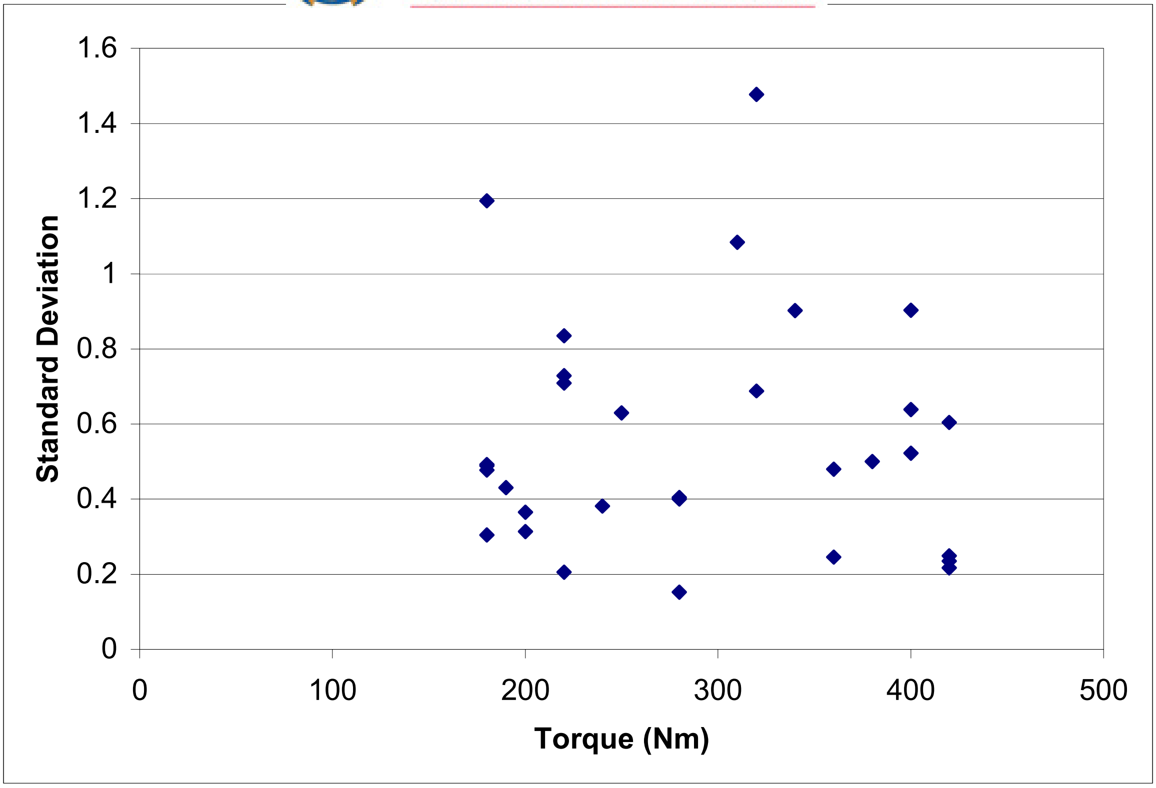


*Figure 6-24 Torque against hole profile standard deviation in machines using dry flushing system*

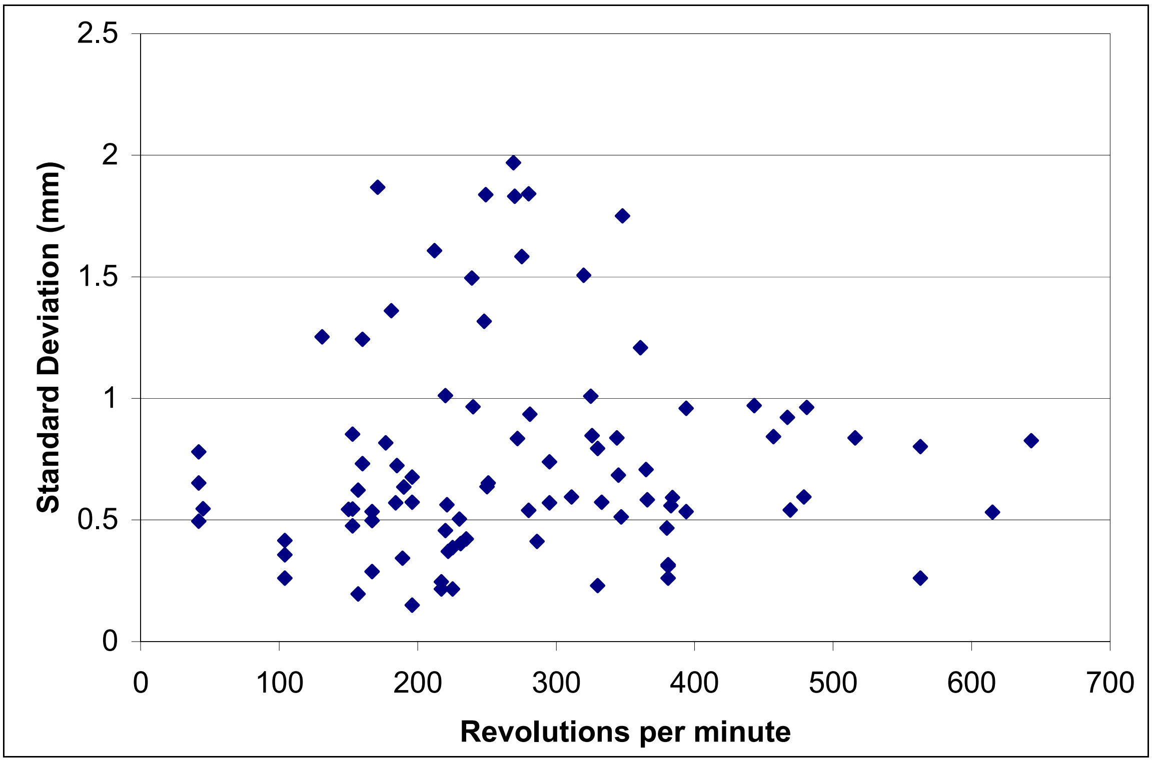


*Figure 6-25 Resin spinning speed against hole profile standard deviation in machines using wet flushing system*

Figure 6-26 and Figure 6-27 show that there is very little difference between standard deviation of hole profiles in sandstone and in the softer materials such as siltstone, shale or coal. While there is more variation in the case of sandstone, in both cases the mean standard deviation is approximately 0.6 mm.

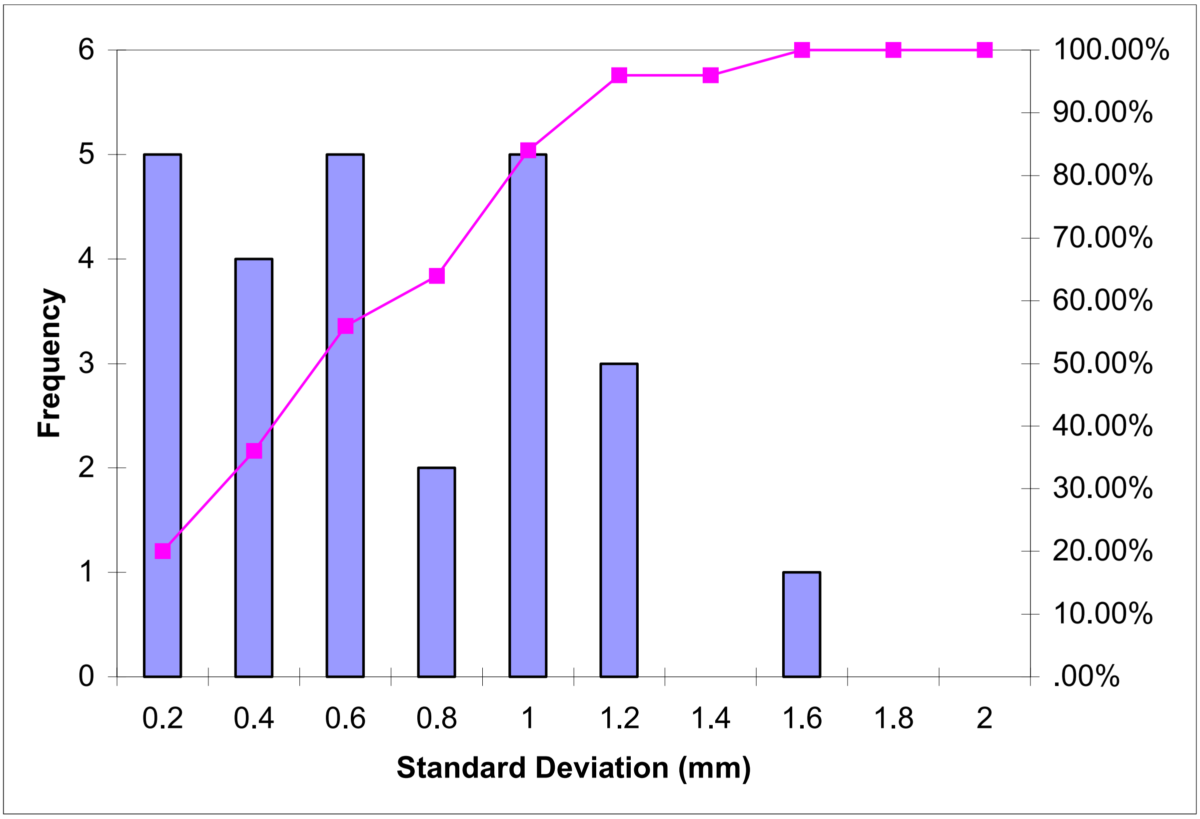


***Figure 6-26 Hole profile standard deviation in sandstone***

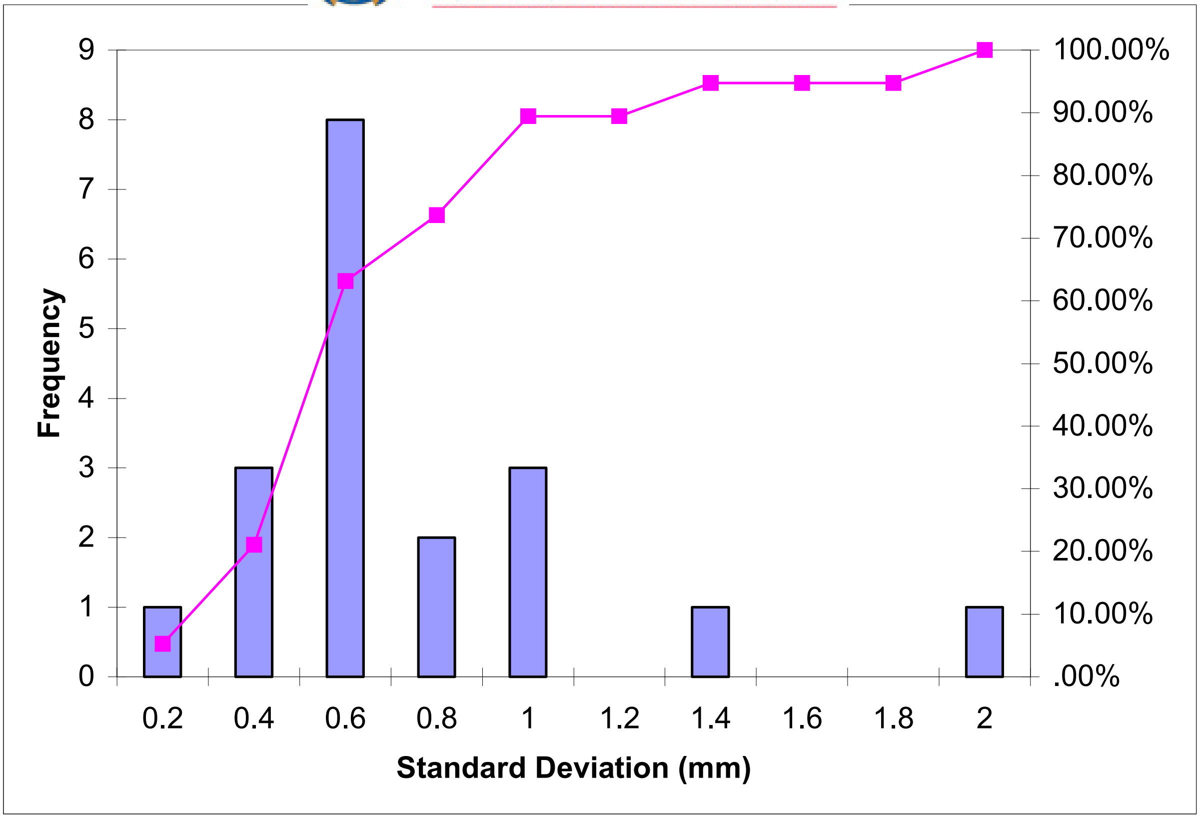


***Figure 6-27 Hole profile standard deviation in 'soft' materials***

### 6.2.4 Effect of wet and dry drilling

The effect of wet and dry drilling is one of the most discussed topics of roof bolting. However, there are not many scientific investigations relating to this effect. Therefore, a total of 24 short encapsulated pull tests (SEPT) using the standard testing procedure of the ISRM (ISRM, 1985) were conducted to determine the effect of wet and dry drilling. These tests were conducted for three different resin types; namely, 15-second resin, 30-second resin and 5/10-minute resin using the same roofbolter, and the same resin from Manufacturer “B”.

Figure 6-28 shows the bond strengths achieved for different resin types using wet and dry drilling. This figure indicates that bond strengths for wet drilling are between 4 to 28 per cent greater than with dry drilling probably due to the fine particles which may be left behind after dry drilling.

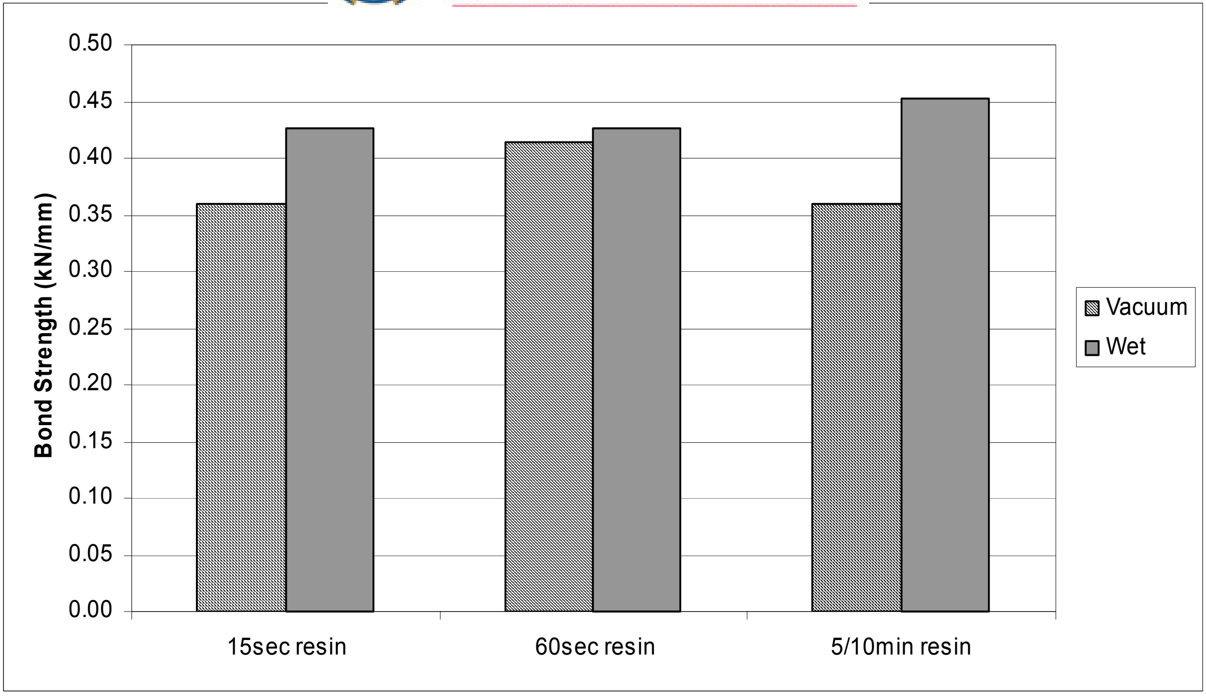


*Figure 6-28 Effect of wet-dry drilling*

Figure 6-29 shows the overall stiffnesses achieved (maximum load achieved / displacement at maximum load) when wet and dry drilling is used for different resins. As can be seen from this figure, the overall stiffnesses are significantly greater for wet drilling than for dry drilling for the faster speed resin types.

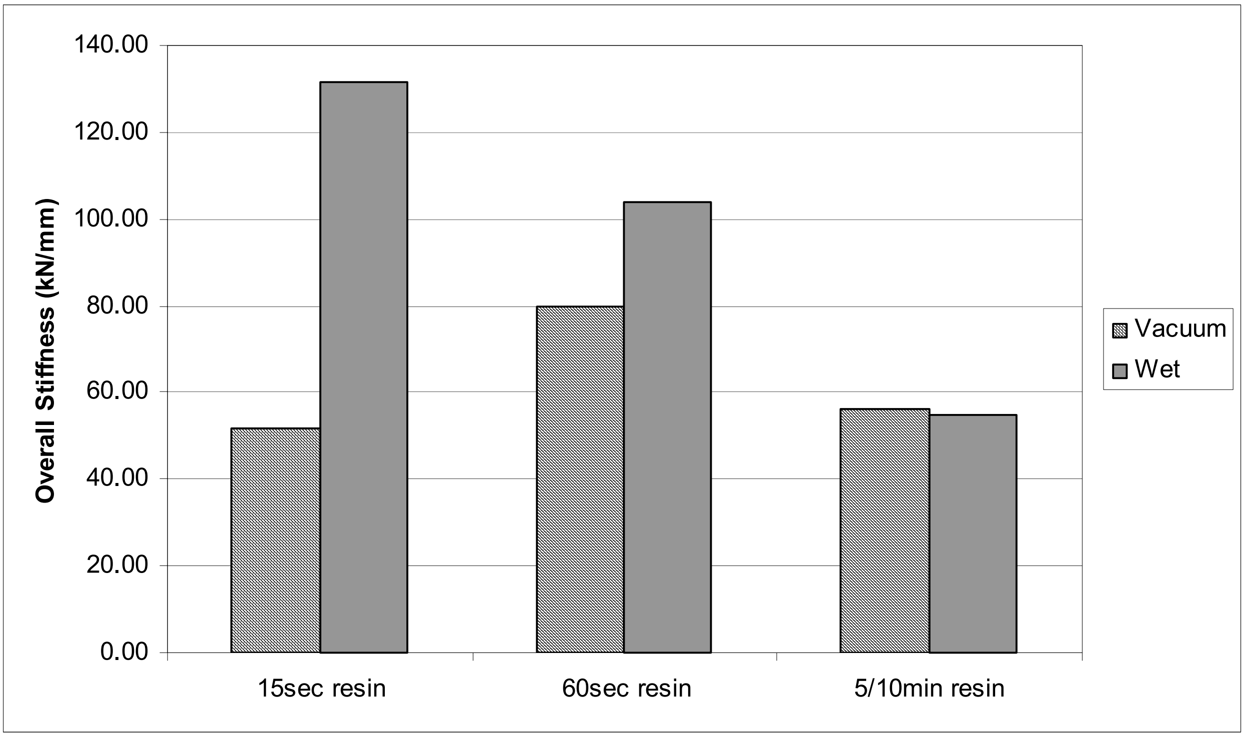


*Figure 6-29 Effect of wet and dry drilling on overall support stiffness*

The data shown in the above figures is presented in Table 6-1.

***Table 6-1 Effect of wet and dry drilling (averages)***

| Rock Type | Drill type | Resin Type | Annulus (mm) | Bond Strength (kN/mm) | Contact Shear Strength (kPa) | Max Load Achieved (kN) | Overall Stiffness (kN/mm) |
|---|---|---|---|---|---|---|---|
| Shale | Vacuum | 15-second | 4.22 | 0.36 | 4029.22 | 90.00 | 51.72 |
| Shale | Wet | 15-second | 3.93 | 0.43 | 4908.03 | 106.67 | 131.71 |
| Shale | Vacuum | 60-second | 4.30 | 0.41 | 4632.19 | 103.33 | 79.88 |
| Shale | Wet | 60-second | 3.63 | 0.43 | 4974.21 | 106.67 | 103.77 |
| Shale | Vacuum | 5/10-minute | 4.55 | 0.36 | 3964.22 | 90.00 | 56.08 |
| Shale | Wet | 5/10-minute | 3.35 | 0.45 | 5404.71 | 113.33 | 55.04 |

## 6.3 Performance of roof bolts

### 6.3.1 Performance of roof bolts manufactured in South Africa

A total of 61 short encapsulated pull tests using the standard ISRM testing procedure (ISRM, 1985) were conducted on 20 mm roof bolts to determine the performance of bolts obtained from four manufacturers.

The results from these tests are shown in Figure 6-30. As can be seen from this figure, bolts from all four manufacturers showed almost identical results in sandstone, while in shale the results were dissimilar. This figure also indicates that bolts from Manufacturer “A” performed relatively better in shale compare to Manufacturer “B”.

As will be shown in the following chapters, the roof bolt profile plays a significant role in determining the pull-out resistance of roof bolts. However, Figure 6-30 indicates that the variation in the performance of roof bolts in sandstone is not significant. In shale, however, there appears to be a significant variation in pull-out strength. This variation can directly be attributed to the profiles of different roof bolts (see Section 6.3.3).

The data shown in the above figure is presented in Table 6-2.

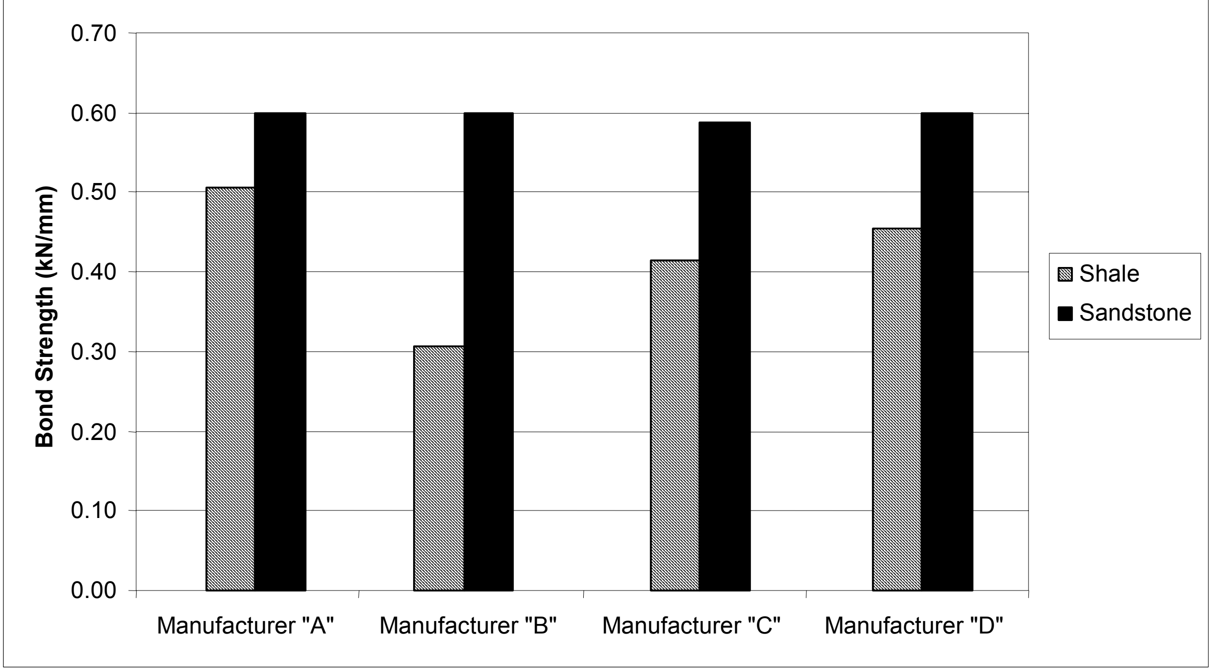


*Figure 6-30 Performance of roof bolts determined from underground SEPTs*

*Table 6-2 Performance of roof bolts determined from underground SEPTs (averages)*

| Rock Type | Manufacturer | Hole Annulus (mm) | Bond Strength (kN/mm) | Contact Shear Strength (kPa) | Max Load Achieved (kN) | Overall Stiffness (kN/mm) |
|---|---|---|---|---|---|---|
| Shale | A | 3.30 | 0.51 | 6036.35 | 126.67 | 101.94 |
| Shale | B | 4.45 | 0.31 | 3406.12 | 76.67 | 81.23 |
| Shale | C | 3.35 | 0.41 | 4920.62 | 103.33 | 40.26 |
| Shale | D | 3.67 | 0.45 | 5318.22 | 113.33 | 23.82 |
| Sandstone | A | 2.96 | 0.60 | 7330.47 | 150.00 | 128.48 |
| Sandstone | B | 3.02 | 0.60 | 7281.30 | 150.00 | 208.77 |
| Sandstone | C | 3.49 | 0.59 | 6926.54 | 146.67 | 30.88 |
| Sandstone | D | 3.50 | 0.60 | 7045.31 | 150.00 | 69.56 |

### 6.3.2 Tensioned versus non-tensioned roof bolts

An additional 25 short encapsulated pull tests were conducted to determine the effect of tensioning on bond strength. These tests were conducted in sandstone and shale roofs.

Figure 6-31 shows the effect of tensioning on bond strength. Non-tensioned roof bolts achieved significantly greater bond strengths then the tensioned bolts. Figure 6-32 shows the effect of tensioning on overall support stiffness. Similarly, non-tensioned roof bolts achieved significantly stiffer systems than the tensioned roof bolts.

Although this finding may be significant from the spin-to-stall support system point of view, it is thought that with tensioned bolts, because the bond length is only 250 mm, the bonding could easily be damaged when the bolt is being tensioned. For this reason it is probable that the test results obtained do not give a fair reflection of the performance of tensioned bolts. It is therefore suggested that a new testing procedure be developed to test the performance of tensioned bolts.

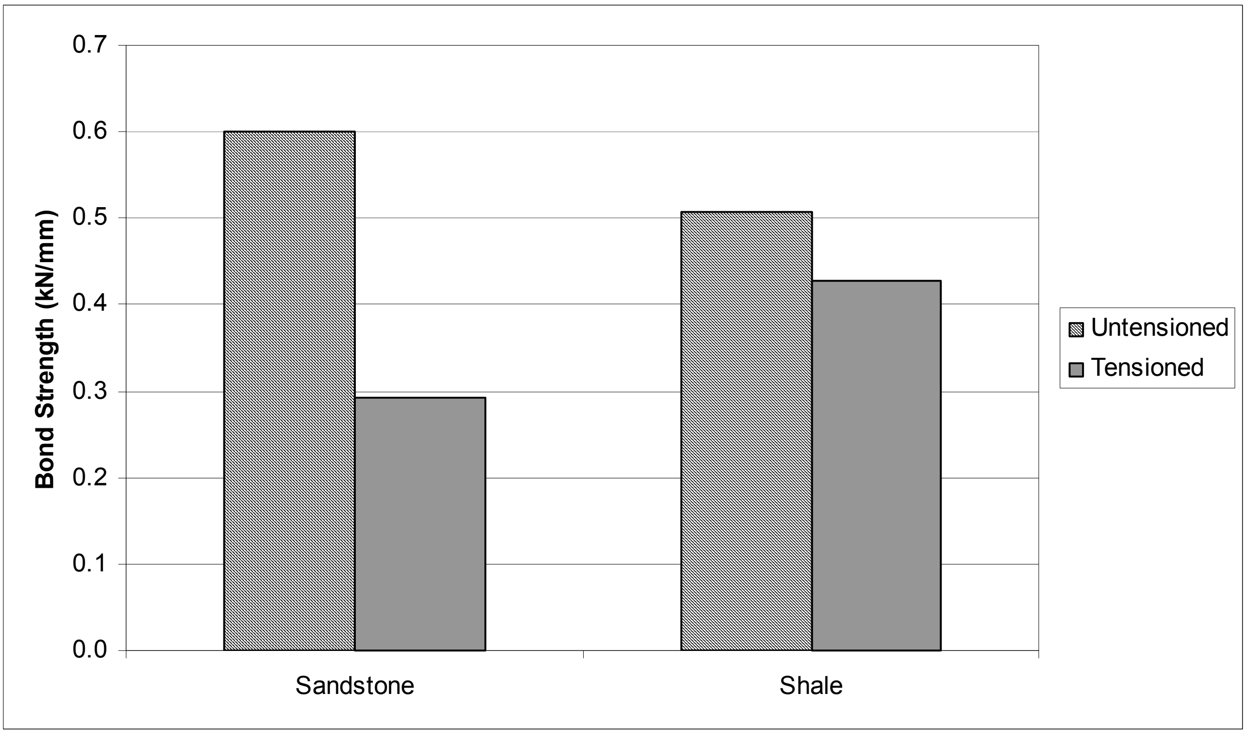


*Figure 6-31 Effect of tensioning on bond strength*

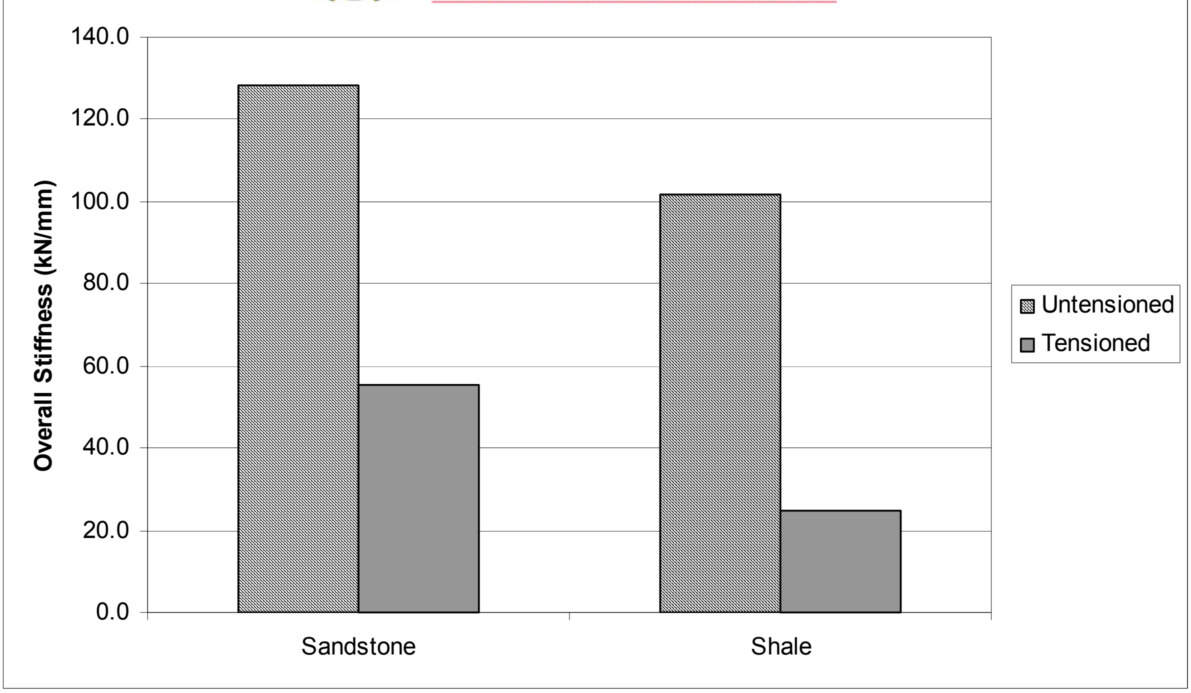


*Figure 6-32 Effect of tensioning on overall stiffness*

The data shown in the above figures is presented in Table 6-3.

*Table 6-3 Effect of tensioning on support performance (averages)*

| Rock Type | Type | Annulus (mm) | Bond Strength (kN/mm) | Contact Shear Strength (kPa) | Max Load Achieved (kN) | Overall Stiffness (kN/mm) |
|---|---|---|---|---|---|---|
| Sandstone | Non-tensioned | 2.96 | 0.60 | 7330.47 | 150.00 | 128.48 |
| Sandstone | Tensioned | 3.87 | 0.29 | 3375.81 | 73.33 | 55.25 |
| Shale | Non-tensioned | 3.30 | 0.51 | 6036.35 | 126.67 | 101.94 |
| Shale | Tensioned 5 | 3.35 | 0.43 | 5131.66 | 106.67 | 24.54 |

### 6.3.3 Variation in roof bolt parameters

In a support system, it may not be possible to control the hole diameter, because of many factors, such as the rock strength, bit type, drilling type, thrust of roofbolter etc. However, it is possible to control the bolt diameter and profile, which is a part of the engineering design. Therefore, an investigation into the variations in the roof bolts that are currently being used in South Africa was conducted by means of measuring the bolt core diameters and rib diameters from different bolt manufacturers in South Africa.

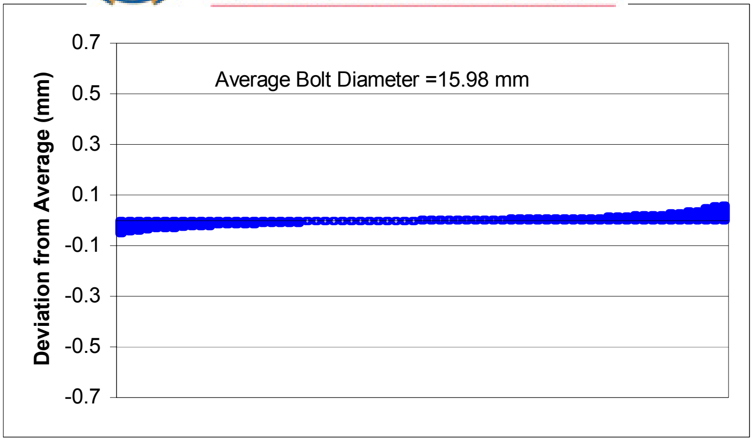
A total of 235 roof bolts from three different manufacturers were evaluated (approximately 80 roof bolts from each manufacturer). The bolts were measured in three places - top, middle and above the thread - to give an average bolt diameter. Rib diameter was measured diagonally across both ribs and bolt core diameter was measured between the ridges, normal to the axis of the bolt.

Bolts of 16 mm diameter were measured from Manufacturers “A” and “B”, and 20 mm roof bolts were measured from Manufacturer “C”. Manufacturer “D” did not supply roof bolts for testing as part of this task of the project. Therefore, they are excluded from this investigation.

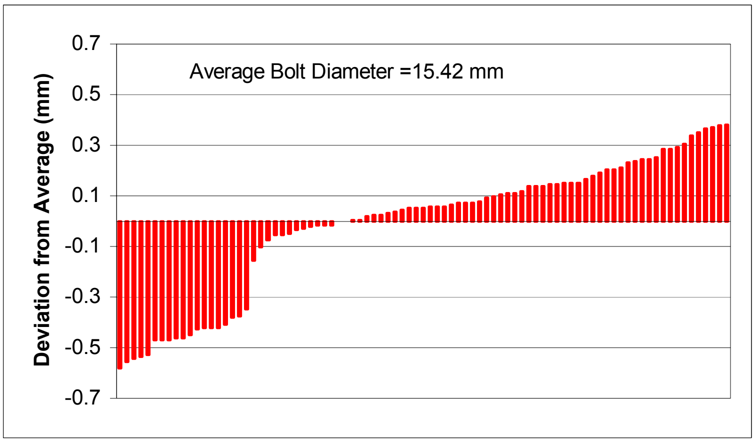
Figure 6-33 shows the deviations of roof bolt diameters (from the average) and the average roof bolt diameters from these three manufacturers. This figure highlights that the deviations from the average diameters of roof bolts from Manufacturers “A” and “C” will be in a significantly narrower range than those from Manufacturer “B”. As shown in Figure 6-30, the bolts from Manufacturer “A” performed relatively better than bolts from Manufacturer “B” in shale rock type.

The rib diameter measurements from these three manufacturers are presented in Figure 6-34. This Figure shows that there is a significant variation in the rib-heights of the roof bolts from Manufacturer “B” and that the average rib-height of roof bolts from this manufacturer is approximately 34 per cent less than those supplied by the other two manufacturers.

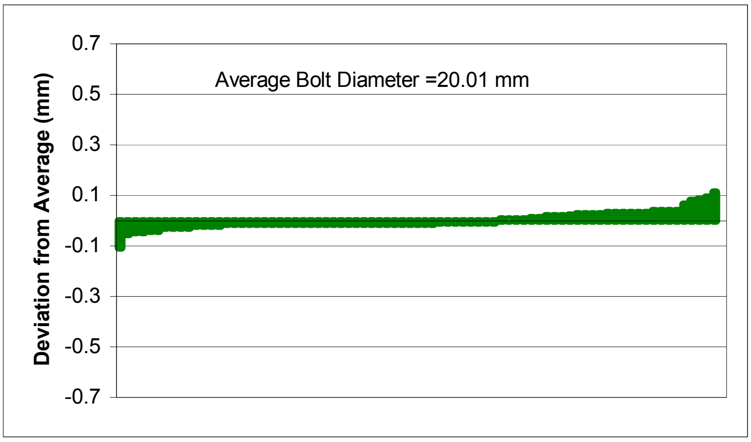
The effect of annulus size on support performance has been shown to be significant. Also, theoretically, a 0.6 mm reduction in bolt diameter can reduce the yield load of a 16 mm bolt by 7 per cent (assuming a tensile strength of 480 MPa). This highlights the need for quality control procedures to be in place at mines for checking the elements of a support system, which are themselves part of the engineering design (roof bolt, bits etc.).



Manufacturer “A”

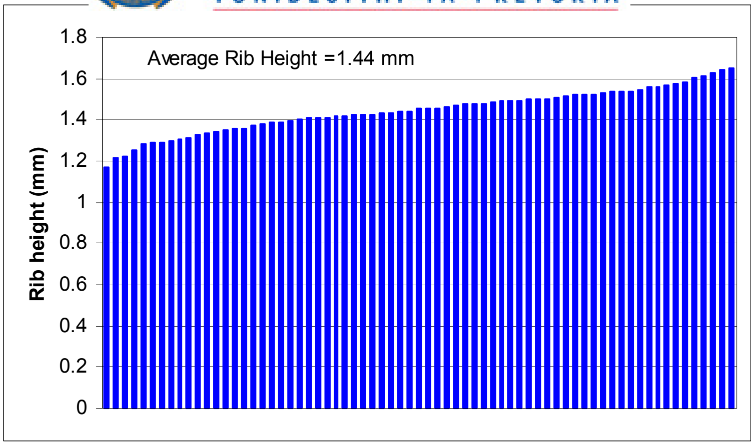


Manufacturer “B”

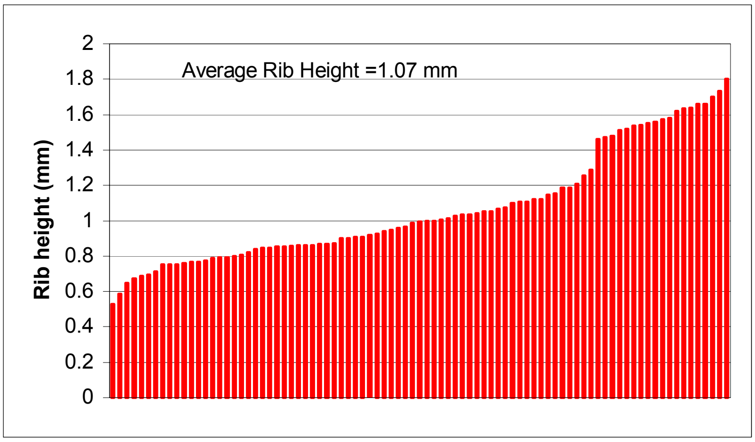


Manufacturer “C”

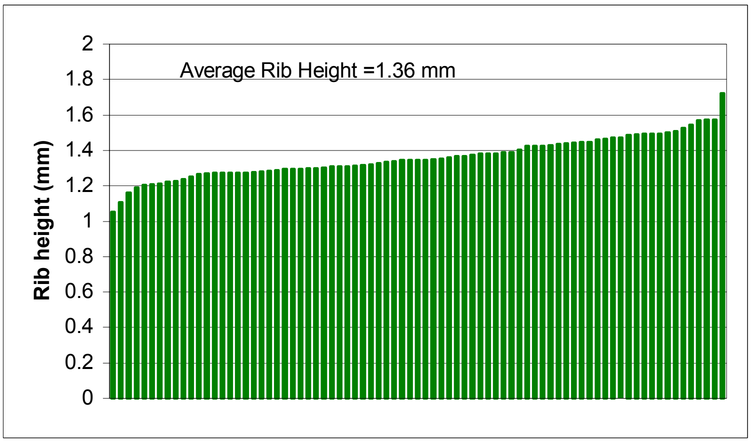
***Figure 6-33 Roof bolt diameter deviations in bolts from three different manufacturers***



*Manufacturer “A”*



*Manufacturer “B”*



*Manufacturer “C”*

***Figure 6-34 Roof bolt rib-height measurements in bolts from three different manufacturers***

An attempt was also made to determine the rib thickness, the spacing between the ribs, and the angle of the ribs of currently used roof bolts in South Africa. Approximately 30 roof bolts from four different suppliers were obtained and three measurements were taken for each bolt. The average results obtained from each manufacturer are shown in Table 6-4.

***Table 6-4 Rib thickness, spacing and angle measured on South African roof bolts***

| Bolt Manufacturer | Rib thickness (mm) | Spacing between the ribs (mm) | Rib angle (degree) |
|---|---|---|---|
| "A" | 3.88 | 8.70 | 64 |
| "B" | 3.02 | 7.33 | 70 |
| "C" | 3.47 | 10.79 | 63 |
| "D" | 3.04 | 9.40 | 60 |
| Average | 3.35 | 9.06 | 64.25 |

As can be seen from this table, there are differences between the parameters that determine the bolt profile in South African roof bolts. Figure 6-35 shows the bolts from the four different manufacturers. However, the influence of these small differences on bolt performance is difficult to determine. It is therefore recommended that a laboratory testing programme be carried out to determine the effect of these parameters on the performance of roof bolts being used in South Africa and to optimise the design.

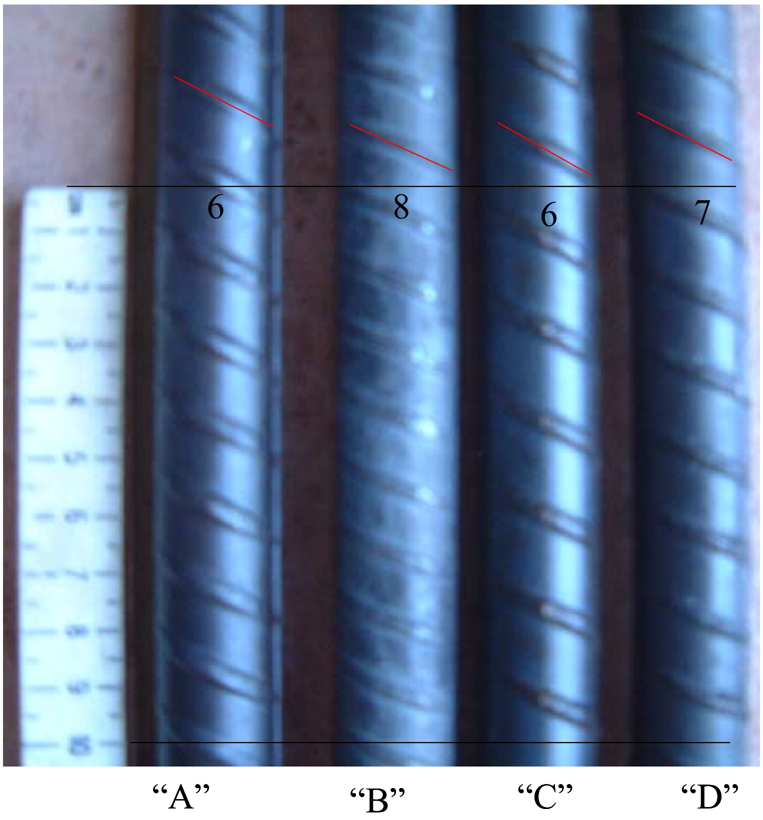


***Figure 6-35 Visual illustration of four South African roof bolts***

Although there are small differences between the South African roof bolts tested, there is a significant visual difference between the AT bolt from the UK and typical South African bolts (Figure 6-36). The angle of ribs between the two types of bolt is significantly different. A detailed sensitivity analysis to the various parameters should be conducted on the resin that would be used and the rock types in which it would be installed in South African collieries.

Roof bolting should be considered as a system and the design of elements comprising the system should be such that the difference in strength between the weakest and strongest element is minimised.

AT Bolt
From UK

South African
Bolt (“D”)

*Figure 6-36 Visual comparison of UK and South African bolts*

## 6.4 Performance of resin

A total of 132 short encapsulated pull tests using the standard ISRM testing procedure (ISRM, 1985) were conducted to determine the performance of various resin types obtained from two manufacturers, namely Manufacturer “A” and Manufacturer “B”.

The results from these tests in three different rock types are shown in Figure 6-37, Figure 6-38 and Figure 6-39. These figures indicate that, in sandstone, 15 second and 30 second resin types from the two different manufacturers performed similarly. However, the performance of slow 5/10-minute resins from both manufacturers was much lower than that of the fast resins. In all short encapsulated pull tests, the bolts were pulled 24 hours after the installation. The large discrepancy between bond strengths for the 5/10-minute resins may be entirely due to not enough waiting time. This finding contradicts with findings of van der Merwe (1989) and therefore should be investigated in detail to determine the effect of slow setting resin on overall system performance by overcoring the full-column resin bolts underground.

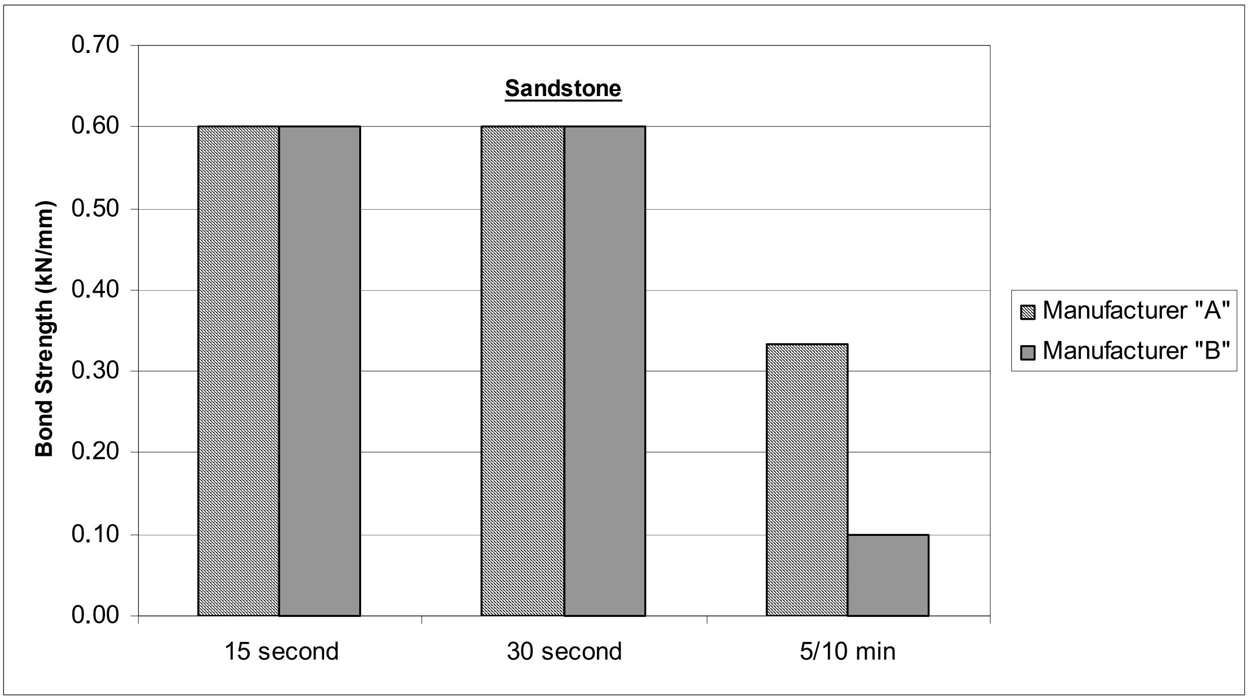


***Figure 6-37 Performance of 15-second and 30-second resin types in sandstone from both resin manufacturers***

No trend could be observed in comparing the resin performance in coal and shale.

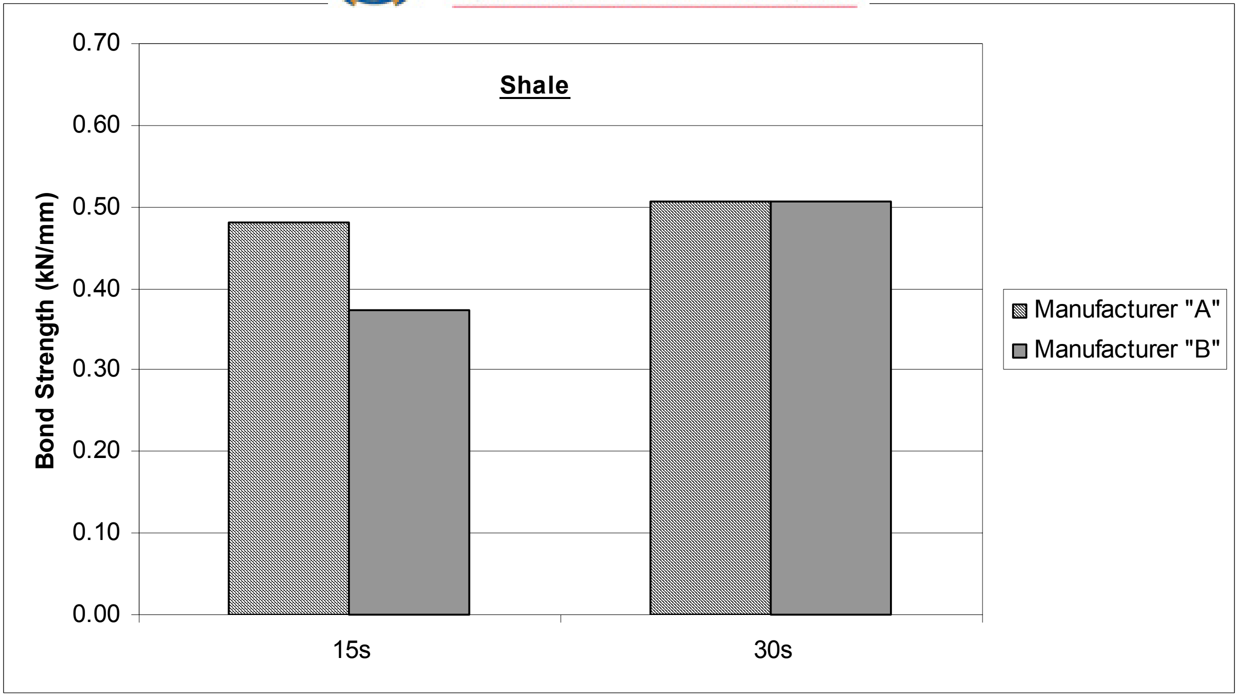


*Figure 6-38 Performance of 15-second and 30-second resin types in shale from both resin manufacturers*

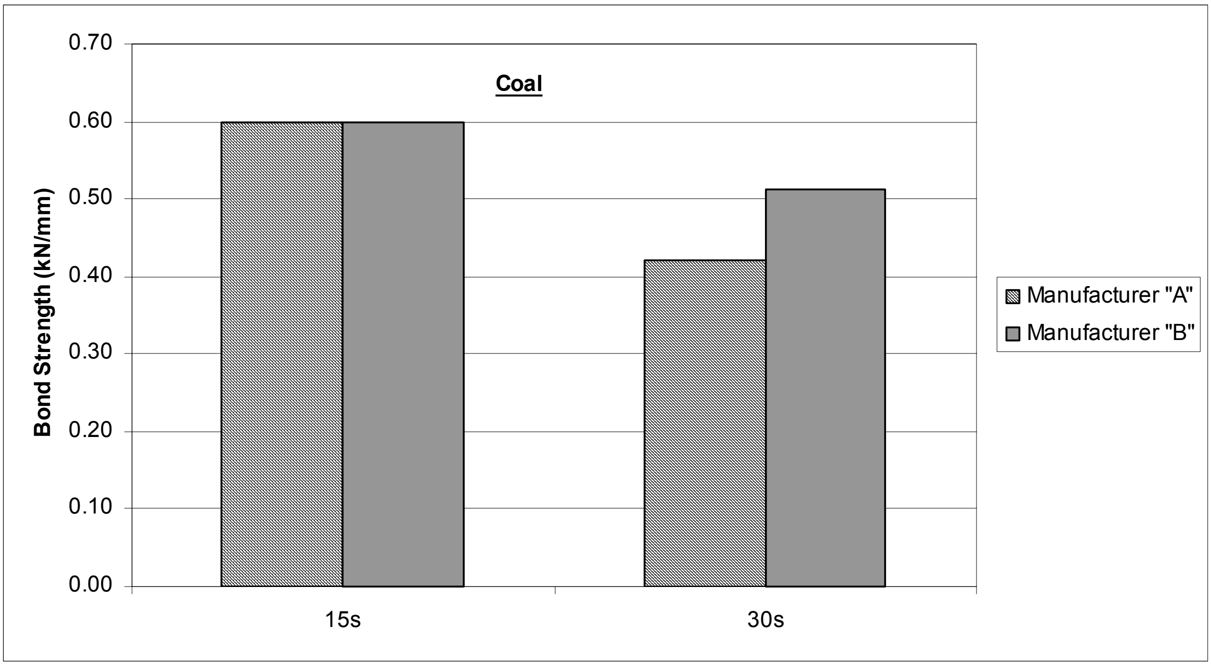


*Figure 6-39 Performance of 15-second and 30-second resin types in coal from both resin manufacturers*

An analysis of the system stiffness of both resin types from both manufacturers was also conducted. The results are shown in Figure 6-40.

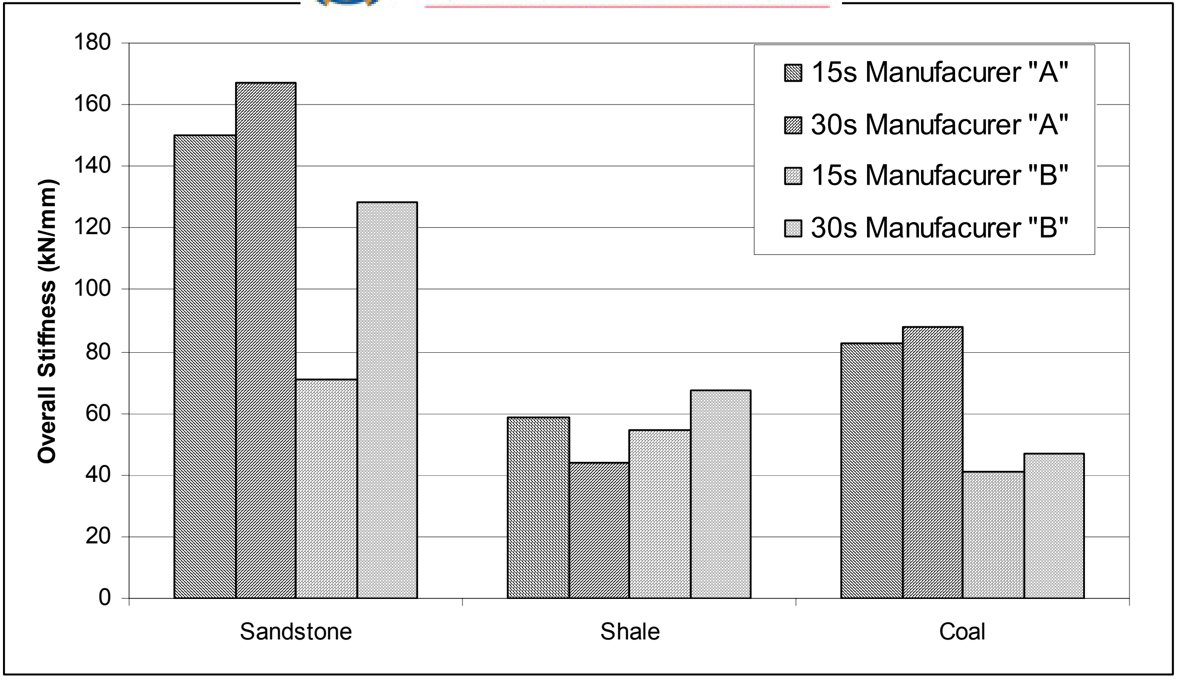


***Figure 6-40 System stiffness of 15-second and 30-second resin types from both resin manufacturers***

Figure 6.4 indicates that both 15-second and 30-second resins from Manufacturer “A” achieved higher stiffness than those from Manufacturer “B” in sandstone and coal. In shale, both resins from both manufacturers performed in a similar manner.

The data shown in above figures is presented in Table 6-5.

***Table 6-5 Overall stiffnesses of resin determined from underground SEPTs (averages)***

| Rock Type | Manufacturer | Resin Type | Annulus (mm) | Bond Strength (kN/mm) | Contact Shear Strength (kPa) | Max Load Achieved (kN) | Overall Stiffness (kN/mm) |
|---|---|---|---|---|---|---|---|
| Sandstone | A | 15-second | 3.37 | 0.60 | 7170.96 | 150.00 | 150.35 |
| Sandstone | A | 30-second | 3.80 | 0.60 | 6980.67 | 150.00 | 167.35 |
| Sandstone | A | 5/10-minute | 3.17 | 0.33 | 4013.31 | 83.33 | 65.56 |
| Sandstone | B | 15-second | 3.01 | 0.60 | 7299.21 | 150.00 | 71.23 |
| Sandstone | B | 30-second | 2.96 | 0.60 | 7330.47 | 150.00 | 128.48 |
| Sandstone | B | 5/10-minute | 3.33 | 0.11 | 1184.60 | 25.00 | 22.03 |
| Shale | A | 15-second | 3.45 | 0.48 | 5689.04 | 120.00 | 58.53 |
| Shale | A | 30-second | 3.37 | 0.51 | 6034.17 | 126.67 | 43.88 |
| Shale | B | 120-second | 3.65 | 0.39 | 4613.01 | 98.33 | 24.51 |
| Shale | B | 15-second | 3.22 | 0.37 | 4497.89 | 93.33 | 54.33 |
| Shale | B | 30-second | 3.30 | 0.51 | 6036.35 | 126.67 | 67.66 |
| Shale | B | 5/10-minute | 3.27 | 0.49 | 5957.16 | 123.33 | 42.99 |
| Coal | A | 15-second | 3.55 | 0.60 | 7056.66 | 150.00 | 82.46 |
| Coal | A | 30-second | 3.43 | 0.42 | 4901.13 | 105.00 | 88.10 |
| Coal | B | 15-second | 3.48 | 0.60 | 7100.73 | 150.00 | 40.86 |
| Coal | B | 30-second | 3.50 | 0.51 | 5963.47 | 128.33 | 47.19 |

## 6.5 Specifications for bolt and resin

The deform pattern of a bolt is an important factor in determining the support system performance. The bolt profile determines three important phases of support installation and performance. These are:

- Quality of resin mixing;
- Pushing the resin towards the end of the hole; and
- Load transfer capabilities of the bolting system.

However, the effect of bolt profile on support performance is poorly understood by the end user. The majority of information pertaining to the design and specification of fully encapsulated roof bolting systems is commercial intellectual property, and little information is available in the public domain. One of the causes of this lack of knowledge regarding the influence of bolt profile on support performance is the testing procedure adopted. When testing the effect of bolt profile, the important factor is the location of the failure mechanism, which should be on the resin-bolt interface. Extensive laboratory short encapsulated pull tests resulted in inconsistent results due to failure taking place on the rock- or pipe-resin interface. In this case, the maximum load in the test is probably independent of bolt profile, assuming that bolt profile did not affect the quality of resin mixing.

The important considerations in a roof bolt profile are depicted in Figure 6-41:

- The rib radius ($R$);
- Rib angle ($\alpha$);
- Distance between the ribs ($p$); and
- Thickness of rib ($d$).

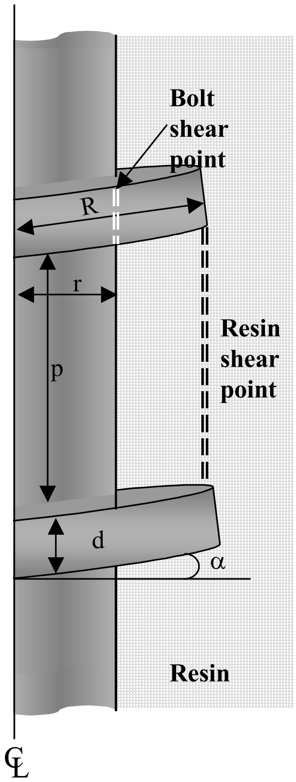


*Figure 6-41 Simplified drawing of roof bolt profile components*

Matching the bolt profile to resin strength is also an important consideration in support system design. In 1999, the South African coal mining industry imported Australian low-rib height roof bolts, which showed relatively poor performance (O'Connor, 2004).

O'Connor (2004) developed a mathematical model to determine the effectiveness of matching resin properties to the profile of the bolt. This model is based on the bolt shearing at the base of the ribs, at the same load as the grout shears between the ribs. O'Connor stated that this happens when:

$$\frac{\text{Resin shear strength}}{\text{Steel shear strength}} = \frac{d\,r}{R\,p} \qquad [6\text{-}1]$$

Where $R$ is the rib radius, $\alpha$ is the rib angle, $p$ is distance between the ribs, and $d$ is the thickness of rib.

This equation indicates that to maintain a balanced performance between resin and roof bolt profile, lower resin strength requires either higher ribs, or longer spacing between ribs, or both of these. Note that this model ignores the effects of resin mixing, film shredding and rib angle.

This model also indicates that the maximum pull-out loads can be achieved between the resin and roof bolt when:

- The ribs are relatively high;
- The distance between the ribs is relatively low; and
- The ribs are relatively thick.

It should also be noted that the failure between the rock and the resin takes place in a similar manner in a short encapsulated pull test. Therefore, the pull-out loads (from SEPT) in stronger rock (such as sandstone) are greater than in softer rock, such as shale (Figure 6-42) due to the nature of greater shear strength of sandstone.

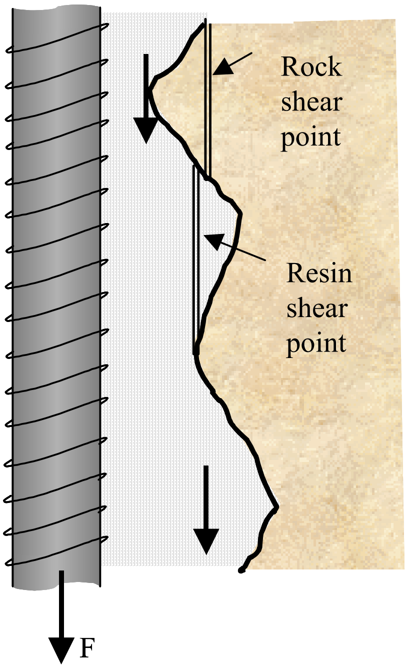


*Figure 6-42 Simplified drawing of failure between the rock and the resin*

As can be seen from Figure 6-42 and Equation [6-1], the pull-out load to failure will increase:

- When the rock shear strength is relatively high; and
- When the hole is rougher.

From all of the above it can be concluded that the failure characteristics of a roof bolting system will be determined by the shear strength of bolt / resin / rock interface:

- The failure will take place at the resin-rock interface when the shear strength of the rock is lower than the resin (rock will fail);
- The failure will take place at either the resin-rock or resin-bolt interface when the resin shear strength is the lowest in the system;
- When the resin shear strength is the lowest in the system, the failure will be determined by the roughness of the hole and the bolt profile.

The other important consideration in the performance of a roof bolt is the bolt geometry (Figure 6-43). The effect of rib angle on the pull-out resistance can be calculated with the use of the following formula:

$$F_R = F \, Cos \alpha \qquad [6\text{-}2]$$

Where $F_R$ is reaction force, $F$ is applied pull-out load and $\alpha$ is rib angle.

Equation [6-2] shows that as the rib angle increases the pull-out load of a bolt decreases. It is therefore suggested that in order for relatively high pull-out loads to be achieved, low rib angles are required. This requirement was confirmed by laboratory tests on different bolts with different rib angles in Australia (O'Brien, 2003). However, lowering the rib angle may result in poor resin mixing performance. It is therefore recommended that further work on the effect of bolt geometry on roof bolt performance be carried out. Such work will then allow the performance of roof bolts to be determined by engineering design that could differ for different rock types. Bolt design could be optimised with the aim of inducing failure on this interface. It is also recommended that the quality of resin mixing should be investigated with different rib angles for determining the most effective rib angles on the roof bolts. Unfortunately, the very similar rib combinations in South African bolt types and testing in an underground environment (uncontrolled conditions) meant that the effect of rib angle, rib height and thicknesses and spacing between the ribs could not be quantified. It is therefore suggested that these tests should be conducted in a controlled laboratory environment.

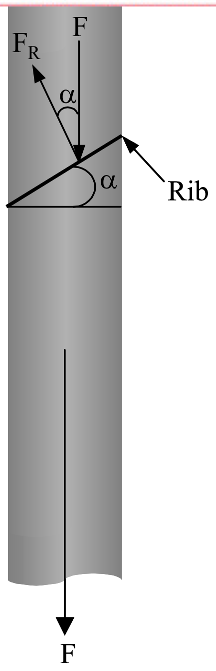


*Figure 6-43 Effect of rib angle on pull-out loads (simplified)*

## 6.6 Effect of bit, annulus and rock type

### 6.6.1 Performance of bits

Two types of drill bits are commonly used in South African collieries. These are the 2-prong bits and the spade bit. Both bits are shown in Figure 6-44.

*Figure 6-44 Spade and 2-prong bits (25 mm)*

A total of 40 short encapsulated pull tests were conducted in order that the performance of the two different bit types could be determined.

The results from these tests in sandstone and shale are summarised in Figure 6-45. As can be seen in the figure, the 2-prong bit outperformed the spade bit in both rock types. However, the annuli obtained from the 2-prong bit were always greater than those from the spade bit (Figure 6-46). This is probably because of rougher holes obtained with 2-prong bits.

The stiffnesses obtained from the 2-prong bits were also greater than those from the spade bit (Figure 6-47). These findings suggest that 2-prong bits are more effective in collieries than the spade bits.

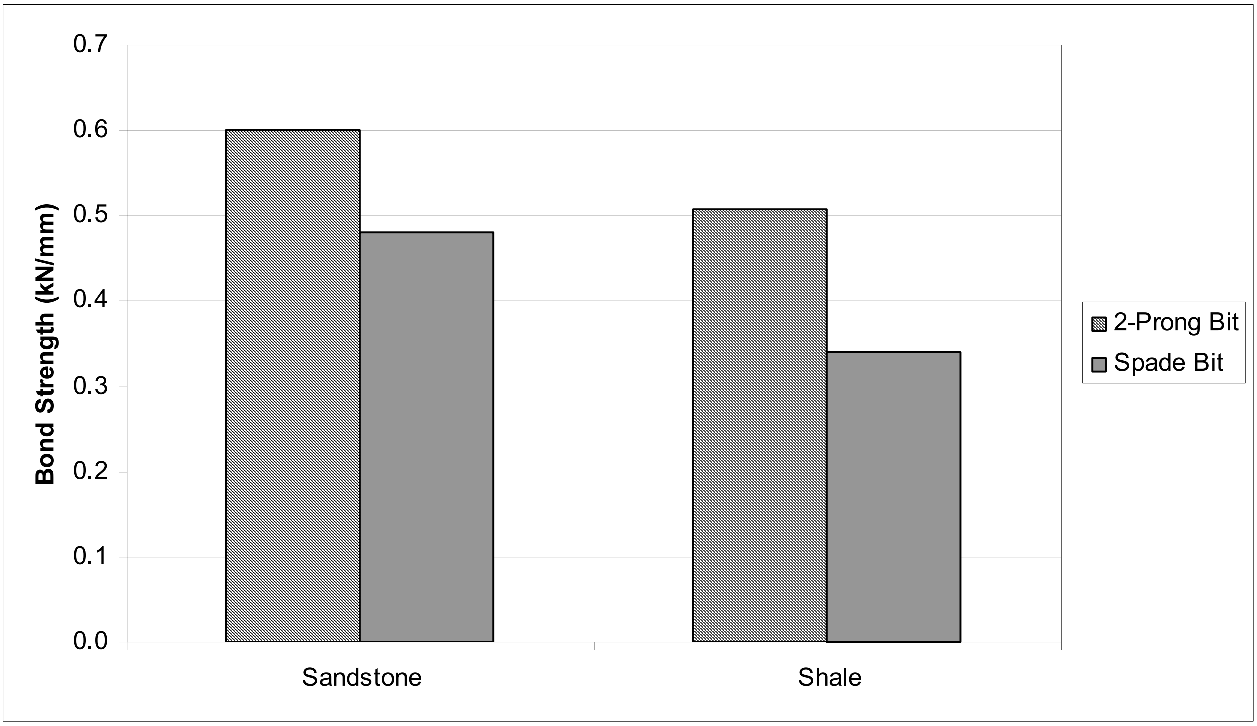


*Figure 6-45 Performance of spade bit and 2-prong bit*

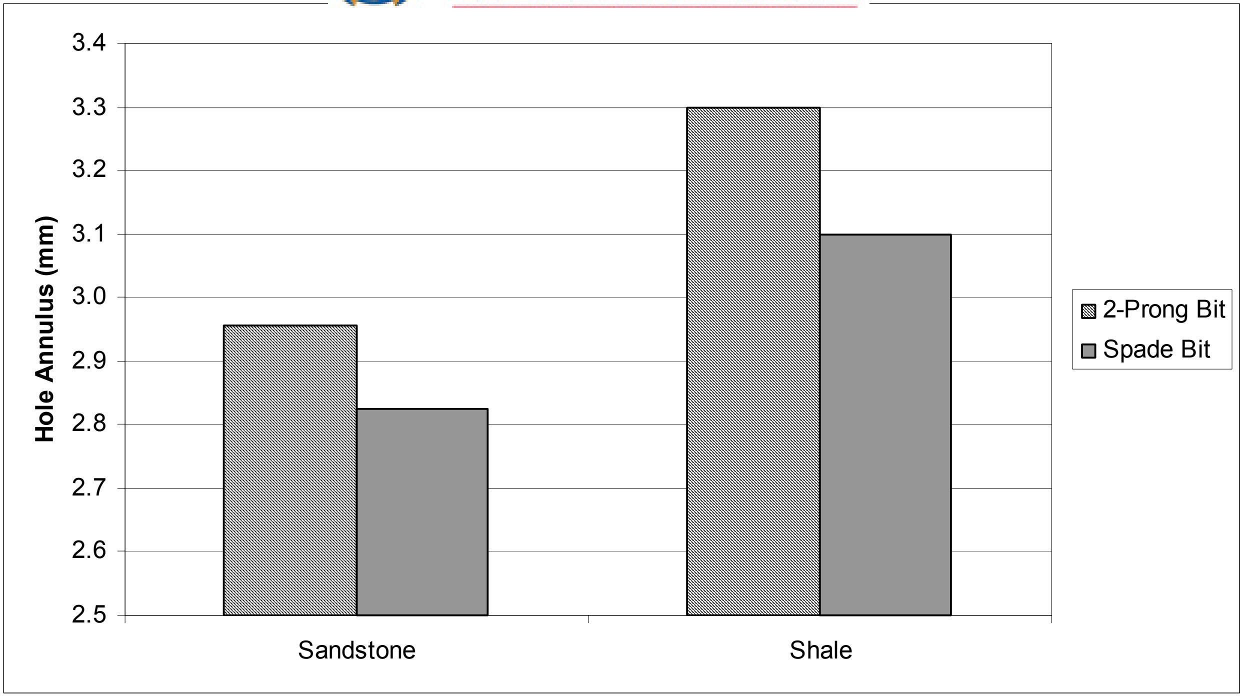


*Figure 6-46 Hole annuli obtained from the 2-prong and spade bits*

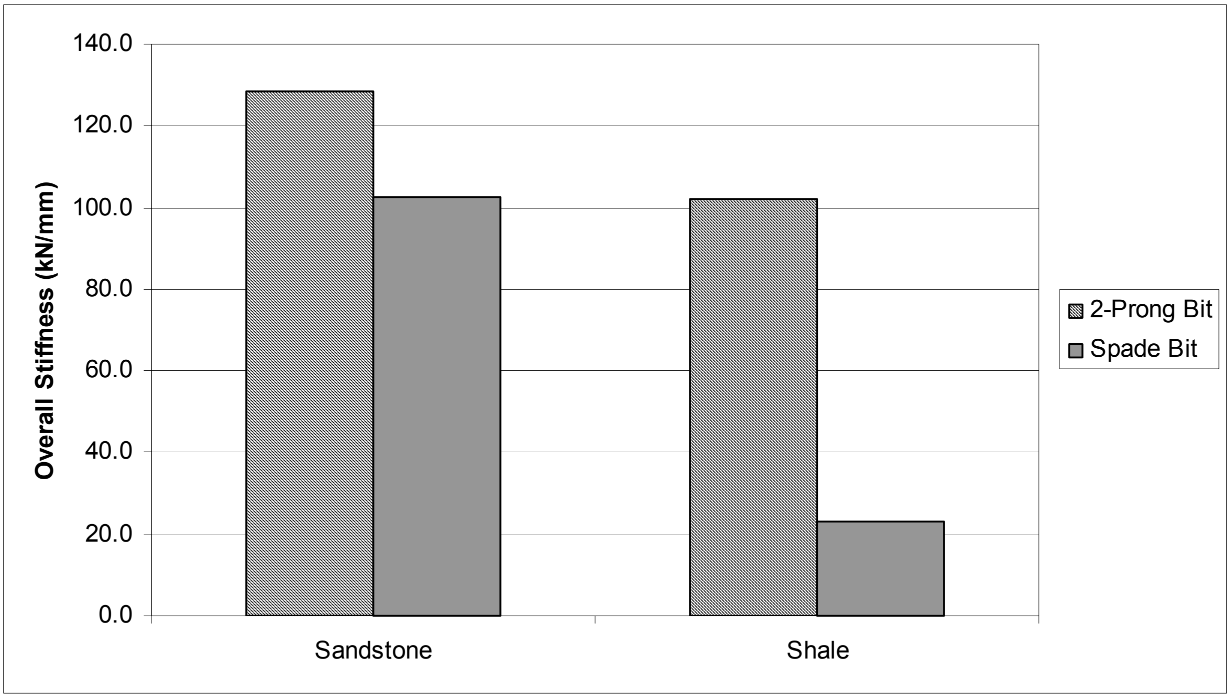


*Figure 6-47 Overall stiffnesses obtained from the 2-prong and spade bits*

The data shown in the above figures is presented in Table 6-5.

***Table 6-6 Performance of bit using SEPT (averages)***

| Rock Type | Bit Type | Annulus (mm) | Bond Strength (kN/mm) | Contact Shear Strength (KPa) | Max Load Achieved (kN) | Overall Stiffness (kN/mm) |
|---|---|---|---|---|---|---|
| Sandstone | 2-Prong | 2.96 | 0.60 | 7330.47 | 150.00 | 128.48 |
| Sandstone | Spade | 2.83 | 0.48 | 5842.97 | 120.00 | 102.35 |
| Shale | 2-Prong | 3.30 | 0.51 | 6036.35 | 126.67 | 101.94 |
| Shale | Spade | 3.10 | 0.34 | 4110.14 | 85.00 | 23.20 |

### 6.6.2 Effect of hole annulus

Borehole annulus is defined as half of the difference between the bolt and hole diameters. As a continuation to the investigation to determine the effect of borehole annulus on support performance, an additional 68 short encapsulated pull tests were conducted under near identical conditions in sandstone and shale roofs. These tests were done using a variety of different sized drill bits in order to attain the necessary annuli. The results from these tests are shown in Figure 6-48.

As can be seen, the results from these tests show that an annulus between 2.5 mm 3.8 mm resulted in the highest bond strengths. Another interesting point is that as the annulus drops below 2 mm, it appears to have a negative effect on the bond strength. This confirms the findings of tests conducted by Hagan (2003) in Australia and the recommendations made by Wagner as far back as 1985.

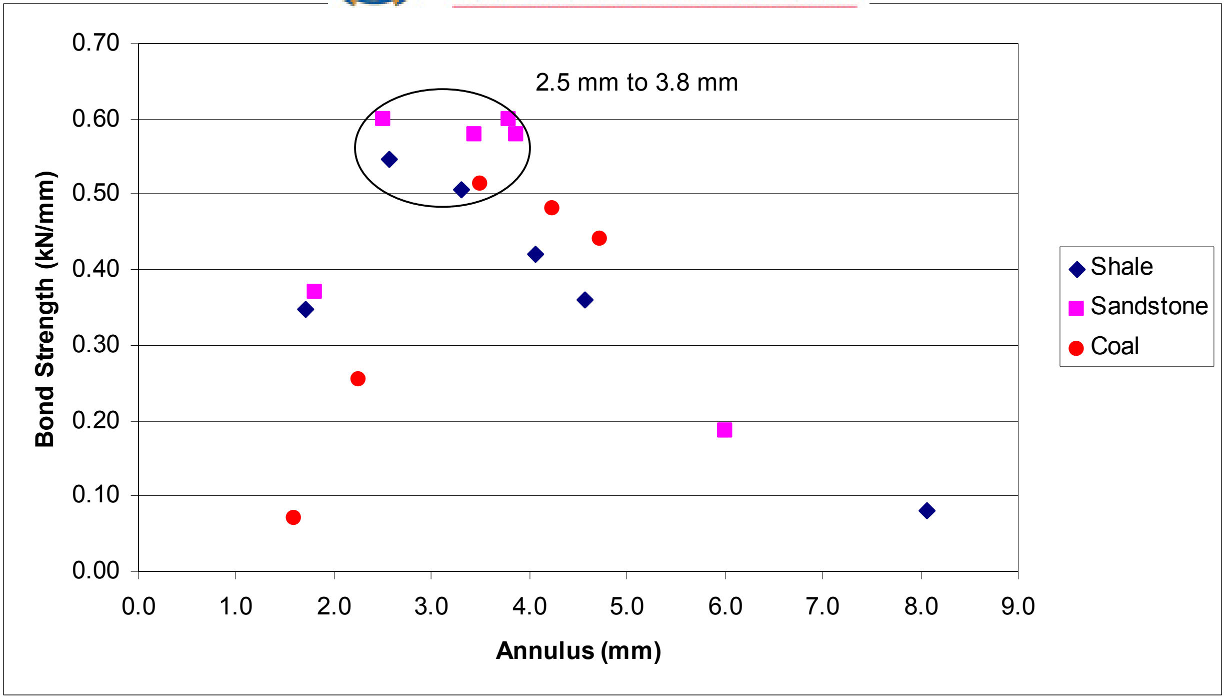


*Figure 6-48 Effect of hole annulus on bond strength*

Note that the annuli in Figure 6-48 are determined from the actual hole and bolt diameter measurements, and not from the bit size. Generally, 24 mm or 25 mm bits with 20 mm roof bolts give an annulus of 2.5 mm and 3.8 mm respectively. It is therefore suggested that these bit sizes should be used with 20 mm roof bolts.

### 6.6.3 Effect of rock types

As has been indicated previously by many researchers, rock type greatly affects support performance. To investigate this effect, a series of pull tests were conducted at different collieries near identical conditions.

Figure 6-49 highlights the very distinct differences between bolt system performances in different rock types. The results clearly show that sandstone produces significantly better results than shale and coal, as was explained in Section 6.5 of this report. From these results it can be concluded that rock type is one of the primary factors influencing support system performance.

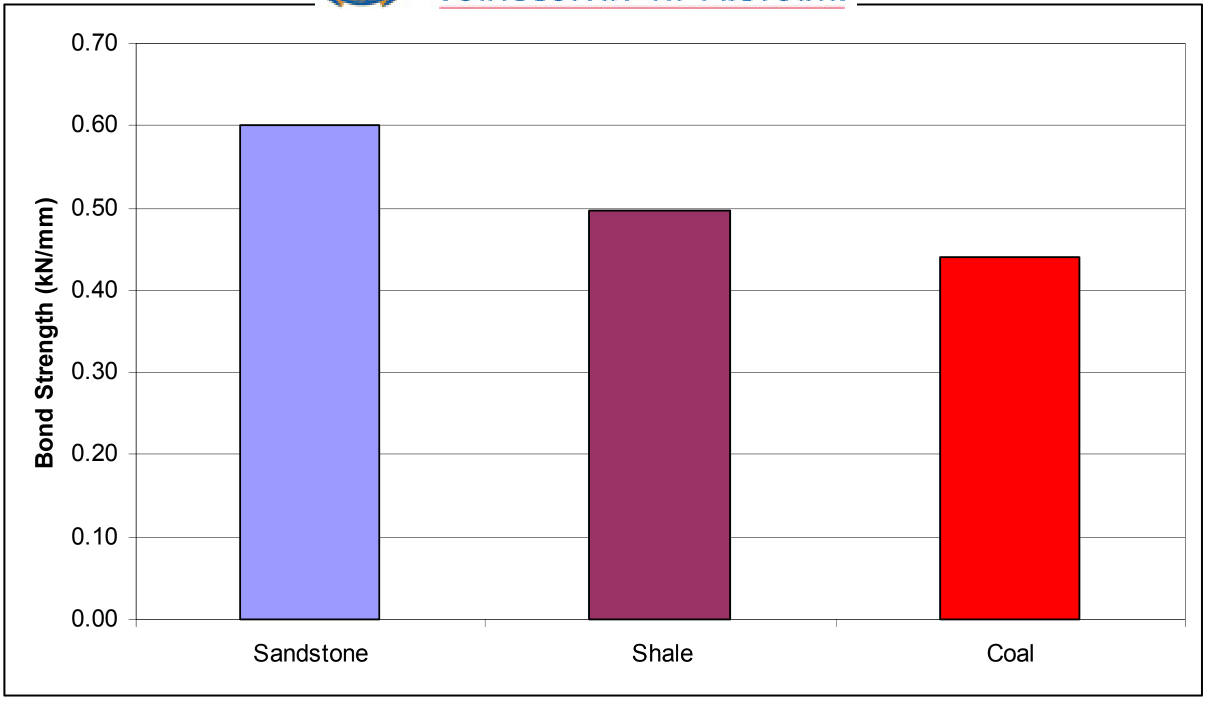


***Figure 6-49 Effect of rock type on support performance***

## 6.7 Quality control procedures for support elements

It is estimated that approximately 6.5 million roof bolts are installed annually in South African collieries (Henson, 2005). Although there are systems available to test the integrity of installed bolts, it is important to ensure that the roof bolts are installed in the best way possible.

There are several factors contributing to the under-performance of roof bolts. These factors should be regularly controlled by systematic quality control procedures.

The factors that can affect the performance of a roof bolt support system can be classified as:

- Direct controllables; and
- Indirect controllables.

The indirect controls are related to suppliers' quality control procedures, such as metallurgical properties of roof bolts, deformation pattern of roof bolts, and chemicals used in the manufacturing process of resin capsules and the consistency of these properties. It is suggested that mining houses should request to examine their suppliers' quality control procedures. It is also suggested that these quality control procedures should comply with ISO standards and that an independent auditor should regularly check for compliance.

The direct controllables can also be divided into three distinct groups (Table 6-7):

- Support elements;
- Compliance with the design; and
- Quality of installation.

As part of this task of the study, currently available quality control procedures established by the mines in South Africa have been reviewed. These systems are the basis of the quality control procedures presented here.

***Table 6-7 A list of direct controllables***

| **Support elements** | **Installation** | **Compliance with the design** |
|---|---|---|
| Roof bolts | Correct installation cycle | Spacing |
| *Strength of roof bolts* | Correct spinning-holding times | Using correct bolt |
| *Correct length* | Correct insertion of resin | Using correct resin |
| *Correct diameter* | Correct drilling | Correct hole size |
| *Corrosion* | Correct bit size | Correct drill bit |
| *Straightness* | Correct rod and hole length | Correct adjustment of roofbolters |
| Resin | Correct flushing | |
| *Strength* | Correct roof bolt pattern | |
| *Storage* | Correct time-to-installation | |
| *Type* | Correct resin storage | |
| Borehole | | |
| *Diameter and annulus* | | |
| *Straightness* | | |
| *Location and inclination* | | |
| *Length* | | |
| *Roughness* | | |
| Roofbolters | | |
| *Torque* | | |
| *Thrust* | | |
| *Speed* | | |
| Accessories | | |
| *Washer strength* | | |
| *Washer size* | | |
| *Nut strength* | | |
| *Threat type* | | |

From the above Table, the following quality control procedures have been recommended in this thesis.

### 6.7.1 Support elements

| ROOF BOLTS | | | |
|---|---|---|---|
| 1 | Length | General | Roof bolt assemblies are to be supplied in standard lengths (see table below) with the provision available for the supply of non-standard lengths at the request of the client. The tolerance on roof bolt length shall be -5 mm +15 mm. |
| 2 | Profile | Diameter tolerance | The maximum tolerance on roof bolt diameters should be within 0.235 mm. |
| | | Rib height | Should meet the SEPT requirement. |
| | | Rib thickness | Should meet the SEPT requirement. |
| | | Rib distance | Should meet the SEPT requirement. |
| 3 | Straightness | General | Deviation form straight must be within 0.4% of the length of the supplied bolt. |
| 4 | Finish | General | The roof bolt must be free of any grease and defects such as burrs, sharp edged seams, laps or irregular surfaces that may affect its serviceability. |
| 5 | Colour coding | General | Colour coding; the base of the threaded portion or forged head (proximal end) of every roof bolt supplied must be colour coded according to the following table:<br>Nominal roof bolt length (m) - Colour coding:<br>0.6 - Orange<br>0.9 - Yellow<br>1.2 - Blue<br>1.5 - White<br>1.8 - Green<br>2.1 - Pink<br>2.4 – Red |
| 6 | End of bolt | General | The non-threaded end of the roof bolt must be free of burrs and edges that protrude beyond the roof bolt profile. Depending on the requirement of the mine: the non-threaded end of the roof bolt must be formed square by cropping; the threaded end of the roof bolt must be acceptably square to the longitudinal axis of the shank; and must be cropped at the distal end at 45º. |

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| 7 | Threaded section | General | The threads are to be roll-formed for 120 mm on the bar and when gauged, must be parallel throughout its length. The basic profile of the thread shall conform to the relevant dimensions specified in DIN 405 Part 1: Knuckle Threads. |
| | Run-out | General | In the thread run-out bolt systems, the thread run-out must not exceed three pitches. |
| | Thread Eccentricity | General | Any thread eccentricity of the roof bolt over a thread length of one roof bolt diameter from the thread run-out of the roof bolt measured at any point on the unthreaded shank within a distance of 1.5 roof bolt diameters from the thread run-out must not exceed 0.70 for the 16 mm roof bolt and 0.84 for a 20 mm roof bolt. |
| | Nib bars | General | Any roof bolt with nibs on the threaded section shall, when tested for mechanical performance, not fracture at the cross-section where the nibs are located. |
| | Nut Break Out | General | Any roof bolt supplied with shear pins or other approved breakout facility will have a breakout force for nuts in the range of 90 Nm to 110 Nm for 16 mm and 140 Nm to 170 Nm for 20 mm. |
| 8 | Mechanical Performance (Resin tendons) | Ultimate tensile strength | The ultimate tensile strength of the roof bolt must be at least 15% greater than the yield stress on each tensile test. |
| | | Yield stress | Minimum yield stress shall be 480 MPa. |
| | | Nibs | Any cross-section nibs located on the threaded section of the roof bolt must not fracture before the specified requirements of the bolt when destructively tested. |
| | | Mechanical properties (Laboratory testing) | **16mm resin tendons or equivalent**<br>Maximum strain at 90 kN: 8 millistrain<br>Maximum strain at 100 kN: 12 millistrain<br>Tendon diameter : 16 mm (± 0.235 mm)<br>Minimum usable thread length: 100 mm |
| | | | **18mm resin tendons or equivalent**<br>Maximum strain at 140 kN: 13 millistrain<br>Maximum strain at 150 kN: 18 millistrain<br>Tendon diameter 17.3 mm (± 0.235 mm)<br>Minimum usable thread length: 100 mm |

| | | | |
|---|---|---|---|
| | | | **20 mm resin tendons or equivalent**<br>Maximum strain at 140 kN: 10 millistrain<br>Maximum strain at 150 kN: 13millistrain<br>Tendon diameter 20 mm (± 0.235 mm)<br>Minimum usable thread length: 100 mm |
| | | Mechanical properties (Underground SEP testing) | The maximum load achieved must not be less than:<br>125 kN for 20 mm roof bolts<br>100 kN for 18 mm roof bolts<br>85 kN for 16 mm roof bolts<br><br>The minimum system stiffnesses must be:<br>20 mm bolt 60 kN/mm<br>18 mm bolt 50 kN/mm<br>16 mm bolt 40 kN/mm |
| 9 | Mechanical Performance (Mechanical bolts) | Underground testing | Performance during underground testing |
| | | | Minimum pull-out load |
| | | | Units must achieve 70 kN of pull-out load. |
| | | | Maximum deformation must not exceed 1.2 times the average deformation attained by the control installations. |
| | | Maximum deformation | Mechanically anchored roof bolts should be provided by Rock Engineering in control installations. |
| | | Control installation | Roof bolts and studs shall comply with the following specifications: |
| | | Specifications | They must have Bail-type or Regular shells, and be equipped with crimp nuts failing at torque equivalent to a pre-tension of 20 kN to 40 kN or Bail-type shells with forged head. |
| | | | Maximum strain at 70 kN: 4 millistrain<br>Maximum strain at 80 kN: 5 millistrain<br>Minimum tendon diameter: 14.5 mm<br>Minimum usable thread length: 100 mm |
| 10 | Washers | General | Washers must be manufactured from steel and must be a minimum of 120 mm x 120 mm square. |
| | | Surfaces | All surfaces must be free of burrs and sharp edges |
| | | Holes | Holes in the dog-eared portion of washers must not be closer then 3 mm to the edge of the washer. |
| | | Shape | Washer plates must be square or round type (deformed or ribbed and with or without dog-ears). |

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| | | Specifications | **For use with 18 mm tendons**:<br>Washers for use with 18mm tendons must meet the following specifications:<br>• Maximum displacement at 140 kN: 13 mm<br>• Maximum displacement at 150 kN: 18 mm |
| | | | **For use with 20 mm tendons:**<br>Washers for use with 20 mm tendons must meet the following specifications:<br>• Maximum displacement at 140 kN: 10 mm<br>• Maximum displacement at 150 kN: 13 mm |
| | | | **For use with all other tendons** |
| | | | Washers for use with all other tendons must meet the following specifications:<br>Maximum displacement at 90 kN: 8 mm<br>Maximum displacement at 100 kN: 12 mm |
| 11 | Nuts | General | Nuts must be of hexagon steel. The dimensions across the flats shall be 24 mm for a 16 mm roof bolt and 32 mm for a 20 mm roof bolt. |
| | | Processing | All nuts are to be cold forged from steel and should be heat treated to provide the required mechanical properties. |
| | | Compliance | Nuts must comply with the relevant requirements for eccentricity and tilt as in SABS 135. |
| | | Compliance | The threads must conform to DIN 405: Part 1 as applicable to nut size. |
| | | Manufacturing process | All nuts must be manufactured from a higher grade steel than the tendon and washer, the steel grade to be a minimum of grade 6. When tested, all nuts must achieve a surface hardness of Vickers 220 to 302HV. |
| | | Performance | When tested to destruction in the laboratory the nut must not fail in any way before the ultimate strength of the tendon is exceeded. The Rock Engineering Department may from time to time call for destructive testing as it sees fit. For routine quality control tests, nuts used with the following tendons must not fail at the following minimum loads: |
| | | | a) Smooth bar (mechanical anchors): 85 kN |
| | | | b) 16mm tendons 110 kN |
| | | | c) 18mm and 20 mm tendons 170 kN |

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| | | Load indicators | One in each ten bolts shall be supplied with a device capable of visually indicating that an installation has been adequately pre-tensioned. During static laboratory testing (not spun or torqued) the indicators must fail at a load of between 45 kN and 55 kN (4.5 to 5.5 tonnes). |
| | | Nut break out | The nut break out facility must operate at the torque range values detailed below:<br>• Bolt Length 0. 9m, 1.2 m - 70 Nm to 90 Nm<br>• Bolt Length 1.5 m, 1.8 m, 2.1 m - 110 Nm to 140 Nm |
| 12 | Drill bits | General | Only the following (nominal) size drill bits should be supplied to mine for the purpose of drilling holes to install ground support material:<br>For resin tendon applications:<br>• For 16 mm and 18 mm roof bolts: 22 mm<br>• For 20 mm roof bolts: 23.5 mm<br>• For cable anchor applications: 36mm<br>• For mechanically anchored roof bolts: 36 or 38mm<br>All drill bits (borers) must be manufactured with a tolerance of -0/+0.25 mm. |

| **ROOFBOLTERS** | | | |
|---|---|---|---|
| 1 | General | | Roofbolters should be regularly maintained, and have the following specifications (note that these specifications are to achieve rough hole profiles, and if necessary, they can adjusted to requirements): |
| 2 | Specifications | Torque | The torque on the roofbolter must be between 220 kN to 250 kN. |
| | | Thrust | The thrust on the roofbolter must be between 12 kN to 18 kN. |
| | | Speed | The speed of the roofbolter must be 350 rpm to 550 rpm. |

| **RESIN** | | | |
|---|---|---|---|
| 1 | General | Capsule | All resin must be supplied in capsule form. |
| | | Compliance | All resin capsules used must conform to SABS 1534:2002. |

| | | | |
|---|---|---|---|
| | | Information required | The following information must be shown clearly on each box of resin:<br>a) Capsule dimensions<br>b) Expiry date<br>c) Batch number<br>d) Spin and hold times |
| 2 | Capsule Size | Tolerance | Capsules must be 19 mm ± 0.5 mm in diameter for use with 16 mm bolts and 23 mm ± 0.5 mm in diameter for use with 20 mm bolts. The tolerance on supplied length must be nominal ordered length +10 /-5 mm when measured between the crimped ends. |
| 3 | Colour Coding | Colour coding | Resin types must be identified by a self-colour coding as given below:<br>• Fast Set – Red<br>• Slow Set – Yellow |
| 4 | Shelf Life | General | All resins must retain their ability to conform to the performance requirements of this specification and retain sufficient rigidity for insertion with a capsule-loading tube for a minimum period of six months when they are stored in accordance with the manufacturer's instructions. |
| 5 | Packaging | General | All packing must be capable of withstanding transportation, handling and storage, and general handling associated with the mining environment. |
| | | Information required | Each package must be identified with the manufacturer's name, type of resin, size of capsule, and quantity of capsules, and be of a colour consistent with the resin-type colour code specified above. |

| | | | |
|---|---|---|---|
| | | Information display | The following additional information must be displayed on all packages in a position that is visible when the packages are stacked:<br>a. Capsule dimensions<br>b. Expiry date<br>c. Batch number<br>d. Nominal mixing and holding time<br>e. Shelf life and storage instructions<br>f. Date of manufacture<br>g. Batch and time reference<br>h. Manufacturer's identification<br>i. The symbols, risk and safety phrases as required under the Safety Regulations<br>j. Remedial measures in the event misuse/accident<br>k. Installation procedure taking into account applicable regulations. |
| 6 | Gel and Setting Time | General | Gel setting times for different spinning speeds and temperatures should be clearly indicated on the box. |
| 7 | Bond Strength and System Stiffness | Performance | When tested in SEPT, the minimum bond strength between roof bolt and resin must be 95 kN for 16 mm bar, 120 kN for 18 mm bar and 140 kN for 20 mm bar. The minimum system stiffness must be 60 kN/mm measured between loads of 40 kN and 80 kN, based on underground pull tests. |
| 8 | Uniaxial Compressive Strength (UCS) | Performance | The UCS of the resin must be greater than 60Mpa when it is measured at least 24 hours after preparation of the test specimens. The number of tests should be determined from the methodology described in this report. |
| 9 | Elastic Modulus | Performance | The elastic modulus of the resin must not be less than 10GPa when it is measured 24 hours after preparation of the test specimens. The required number of tests should be determined from the methodology described in this report. |
| 10 | Creep | Performance | The creep of the resin must be no more than 0.12% when it is measured 24 hours after preparation of the test specimens. |
| 11 | Shear strength | Performance | Must meet the SEPT requirements.<br>The maximum load achieved must not be less than:<br>125 kN for 20 mm roof bolts<br>100 kN for 18 mm roof bolts<br>85 kN for 16 mm roof bolts |

| | | | |
|---|---|---|---|
| | | | The minimum system stiffnesses must be:<br>20 mm for bolt 60 kN/mm<br>18 mm for bolt 50 kN/mm<br>16 mm for bolt 40 kN/mm |

| **ROUTINE TESTS** | | | |
|---|---|---|---|
| 1 | Roof bolts | Mechanical properties | At least 5 bolts from each batch supplied to the mine should be tested in the laboratory. |
| | | Length | As a routine test, one roof bolt in every 200 produced must be checked for length using a measuring tape. |
| | | Diameter | As a routine test, one roof bolt in every 200 produced must be checked for diameter using a Vernier. |
| | | Straightness | As a routine test, one roof bolt in every 200 produced must be checked for straightness using an appropriate gauge. |
| | | Rib height | As a routine test, one roof bolt in every 200 produced must be checked for rib height using a Vernier. |
| | | Washer | At least 5 from each batch should be tested in the laboratory. |
| | | Thread | As a routine test, one roof bolt in every 200 produced must be checked for thread. |
| | | Nuts | At least 5 from each batch should be tested in the laboratory. |
| 2 | Resin | Length | As a routine test, one resin in every 10 boxes produced must be checked for length using a Vernier. |
| | | Diameter | As a routine test, one resin in every 10 boxes produced must be checked for diameter using a measuring tape. |
| | | Mechanical properties | At least 5 from each batch should be tested underground using short encapsulated pull tests. |
| 4 | Roofbolters | Torque, thrust and speed | As a routine test, roofbolter’s torque, thrust and speed must be checked once every month. |

### 6.7.2 Compliance with the design

Compliance with the design should be checked underground at least once every fourth week. The following parameters should be measured and recorded:

- Spacing of roof bolts using a simple measuring tape;
- The use of correct bolt type;
- The use of correct resin type;
- Correct hole size using a borehole micrometer;
- The use of the correct drill bit; and
- Correct adjustment of torque, thrust and speed of roofbolters using a torque wrench, load cell and tachometer, respectively.

### 6.7.3 Installation

Underground support installation is one of the most important aspects of support performance. The following parameters should be measured and recorded every fourth week using the appropriate instruments, where necessary:

- Correct installation cycle;
- Correct spinning-holding times;
- Correct insertion of resin;
- Correct drilling;
- Correct bit size;
- Correct hole size;
- Correct rod length and hole length;
- Correct flushing;
- Correct roof bolt pattern;
- Correct time-to-installation; and
- Correct resin storage.

## 6.8 Conclusions

Although a considerable amount of time was spent on the effect of the roofbolters on the performance of support systems, few trends could be observed in the parameters influencing the support performance. The study showed that there are no standards in South Africa for the parameters investigated (speeds, torque, and thrust). Underground testing showed that the variations in the parameters are greater than was previously believed. No correlation between the hole profiles and the parameters investigated could be discerned.

Nevertheless, this indicates that in South Africa, the installation quality of bolts varies significantly. Irrespective of design, the bolts are installed in completely different manners. Unfortunately, there is no data available on the relationship between roof collapses and the quality of bolt installation. It is therefore impossible to determine empirically which support installation performs the best. This highlights a need for the best equipment performance for the best support installation to be investigated in detail. Such a study would assist in reducing the falls of ground and, therefore, the rock-related casualties in South African collieries. However, experience gained during the underground experiments showed that such work can only be done in a more controlled environment, such as with the laboratory.

Five important elements of a bolting system have been identified. The impacts of those elements were qualified through short encapsulated pull tests.

The performance of roof bolts that are currently supplied to South African mines was also investigated by a series of short encapsulated pull tests. The results indicated that bolts from all four manufacturers showed almost identical results in sandstone, while in shale the results were dissimilar.

To determine whether variations in the profile of bolts supplied by the different manufacturers could account for the differences in performance, the bolt-core diameters and rib diameters from different bolt manufacturers in South Africa were measured.

The parameters that determine the contact strength between bolt and resin are rib-height, spacing between the ribs, and the rib angle. An investigation was conducted into the dimensions of roof bolts that are used currently. The results showed insignificant differences between the parameters that determine the bolt profile of South African roof bolts. Owing to the physical similarity between the bolts studied, it was not possible to determine the influence of these parameters.

The effect of rib angle was investigated and the results of a literature search showed that, as the rib angle increases away from normal to the bolt axis, so the pull-out load of the bolt decreases. It is therefore suggested that, in order to achieve relatively high pull-out loads, low rib angles on the bolts are required. This was confirmed by laboratory tests on different bolts with different rib angles in Australia (O'Brien, 2003). However, it is noted that lowering the rib angle may result in poor resin mixing performances.

Using a conceptual model to determine the effect of bolt profiles, it is shown that maximum pull-out loads can be achieved between the resin and roof bolt when:

- The ribs are relatively high;
- The distance between the ribs is relatively low; and
- The ribs are relatively thick.

The performance of resins that are currently being used in South African collieries was also investigated by means of short encapsulated pull tests. The results indicated that in sandstone the resin types from the two different manufacturers performed similarly. However, the strength of slow (5/10-minute) resins from both manufacturers was much lower than that of fast resins. It is concluded that in the majority of pull tests, failure took place at the rock-resin interface, indicating that the rock failed before the resin shear strength had been reached. It is therefore suggested that the strength of resin currently being used in South Africa is adequate. However, the stiffness of the system of which resin is a part should be determined by short encapsulated pull tests.

Again, the conceptual model developed to determine the effect of resin in the support system concluded that the failure characteristics of a roof bolting system will be determined by the shear strength of bolt, resin, and rock.

- The failure will take place at the resin-rock interface when the shear strength of the rock is lower than the resin (rock will fail).
- The failure will take place at either the resin-rock or resin-bolt interface when the resin shear strength is the lowest in the system.
- When the resin shear strength is the lowest in the system, the failure will be determined by the roughness of the hole and the bolt profile.

The test results showed that the reinforcing system using bolts from all four manufacturers performed almost identically in sandstone, but performed in different ways in the other rock types. The bolts from Manufacturer "A" performed slightly better in coal and shale rock types than the bolts from other manufacturers.

In order to investigate the effect of bit types, a series of short encapsulated pull tests were conducted. The results showed that the 2-prong bit outperformed the spade bit in sandstone and shale rock types. However, the average hole annuli obtained from the 2-prong bit were always greater than the spade bit. It is thought that this is because 2-prong bits drilled a rougher hole profile. Both the stiffness and the maximum load obtained from the 2-prong bits were greater than for the spade bits. These findings suggest that 2-prong bits are more effective in collieries than spade bits are.

The effect of hole annulus was also investigated. The results show that an annulus between 2.5 mm 3.8 mm resulted in the most effective bond strengths. Another interesting point is that as the annulus drops below 2 mm, it appears to have a negative effect on the bond strengths.

The effect of wet and dry drilling was also investigated by means of short encapsulated pull tests. The results showed that bond strengths and overall support stiffnesses are greater with the use of the wet drilling in all three resin types. The reason for this was not determined but is probably related to the surface condition of the holes and its influence on the adherence of the resin to the rock.

Tensioned versus non-tensioned bolts is one of the most discussed topics in roof bolting. A number of papers have been published on this topic in Australia and the US. An additional 25 short encapsulated pull tests were conducted to determine the effect of tensioning on bond strength. The results showed that non-tensioned roof bolts achieved significantly higher bond strengths than the tensioned bolts in sandstone and shale roofs. Similarly, the overall support stiffness of non-tensioned roof bolts was significantly greater than that of the tensioned roof bolts. This finding may be significant and therefore the effect of tensioning and non-tensioning on overall support system performance should be investigated in a control environment.

The effect of rock type on support performance was also investigated by means of a series of short encapsulated pull tests. The results from these tests highlight the very distinct differences between bolt system performances in different rock types. Sandstone was shown in the tests to produce significantly better results than shale and coal. From these results it can be concluded that rock type is one of the primary factors influencing the support system performance.

An investigation into the quality control procedures of support systems was also conducted. Quality control procedures for compliance with the design, support elements and quality of installation are presented in the thesis. Recommendations for improving quality control measures and for developing testing procedures for bolt system components, installation quality and resin performance are provided.

Most importantly, similar to stress regime, geology and roof characteristics presented in the previous Chapters, there is a significant variation in the performance of support systems using different support components in different geotechnical environments. Therefore, it is concluded that a deterministic approach is not adequate for a roof bolting system design in such a complex system. A probabilistic approach is required in order to take all these variations into account.