LATEST SOUTH AFRICAN TECHNOLOGY: "MINECRETES3 SHOTCRETE HYBRID.
ACCELERATED SETTING WITH HIGHER STRENGTHS AND INCREASED PRODUCTIVITY. NEW TRANSPORT TECHNOLOGY OF MOBILE BATCHING PLANTS FOR CONCRETE.

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INTRODUCTION
Conventional shotcrete as we know it, requires a batching plant, barrel mixer and robotic sprayer. This is the support system used for the majority of the underground mines throughout the world today. Deeper mining, requires a thicker shotcrete application. The material volumes required for the application of shotcrete as well as distance they travel, increases their costs and lowers productivity.

With the challenges that the mines face, we have developed a new wet shotcrete called MineCreteS3 (MCS3) Shotcrete Hybrid, a first of its kind. It is a three part mix which consists of cement, aggregate and water. Additives such as retarders, accelerators, plasticizers, fly ash and silica fume, are no longer needed. MCS3 comes in powder form with all additives mixed and blended with the option of fibre premixed. Why do we call MCS3 a "Hybrid shotcrete" it is because we have combined the advantages of a TSL and the advantages of wet shotcrete. TSL’s use polymers to create high tensile, tensile bond and shear bond strengths which shotcrete do not have. Conventional shotcrete uses compression strength and energy absorption to create a structural support system that can work safely in any type of rock, especially in bad and very poor ground conditions with high deformations and presence of water. MCS3 Super Strong Shotcrete", has structural strength developed by higher strengths in tensile, tensile bond, shear bond, compression and energy absorption. The fact that MCS3 has such superior strengths and setting times it allows you to reduce your thicknesses by up to 50%, which translates into a considerable saving in transport to the mine, materials handling on surface as well as underground, increasing your rate of application underground, allowing for more blast per shift. MCS3 will reduce dust pollution at the nozzle due to the thixotropic (viscosity), which substantially improves visibility and safety.

Another breakthrough in technology introduces the volumetric mixer for fast, controlled and precise mobile plant batching to be mixed at the required area of application. This eliminates the need for surface and underground batching plants. The use of barrel mixers (aggie cars) will no longer be needed. A volumetric Mixers is a mobile batching plant that transports all the materials needed (MCS3 cement, aggregate, fibres and water) separately and then mixed together at the required site ready for application. The volumetric mixer will be compatible with all existing robotic piston pumps the mine already has. The equipment also only requires one operator.

DEFINITION OF THE PROBLEM
The main objective is to maximise profitability, in the shortest time possible, at the lowest cost without accidents. As underground mining goes deeper, the stress conditions are increased. This increases the need for new inventive ways of introducing new support systems to help the mines achieve their goals by reducing the risks of fatality’s underground and down time. To solve this problem a new type of shotcrete
called “MCS3” a shotcrete hybrid has been developed.

BACKGROUND
For 20 years, deep level mining in South Africa have been using "Thin Spray-On Liner - TSL". The main function of these products is to penetrate and seal the fractures in the rock mass to avoiding the oxidation and weathering of problematic rock for long term mining. TSL’s have high strengths in tensile, shear bond and tensile bond compared to shotcrete, as shown in figure 1. These properties are fundamental for the design of all types of TSL’s. The important properties of conventional shotcrete (dry or wet) commonly only look at compression and energy absorption (Efnarc). Table 1 shows the typical resistance of shotcrete in compression. The MCS3 Hybrid Shotcrete was developed as a combination of TSL’s and shotcrete to give the customer the best of both products in one.

Table 1. Example of early ages and 28 days of shotcrete in a tunnel construction. (4)

<table>
<thead>
<tr>
<th>Age</th>
<th>Minimum strength (MPa)</th>
<th>Test applied</th>
<th>Elastic modulus (MPa)</th>
</tr>
</thead>
<tbody>
<tr>
<td>3 hours</td>
<td>1 MPa</td>
<td>Initial Strength</td>
<td>1,000</td>
</tr>
<tr>
<td>12 hours</td>
<td>6 MPa</td>
<td>Penetrometer</td>
<td>12,000</td>
</tr>
<tr>
<td>24 hours</td>
<td>18 MPa</td>
<td>Sprayed Beam Compression (ASTM C116)</td>
<td>20,000</td>
</tr>
<tr>
<td>3 days</td>
<td>26 MPa</td>
<td>Compression Strength (AS1012)</td>
<td>24,000</td>
</tr>
<tr>
<td>7 days</td>
<td>35 MPa</td>
<td>Compression Strength (AS1012)</td>
<td>28,000</td>
</tr>
<tr>
<td>28 days</td>
<td>40 MPa</td>
<td>Compression Strength (AS1012)</td>
<td>30,000</td>
</tr>
</tbody>
</table>

SHOTCRETE FAILURE MODES
The principle of a support system is to provide a structural membrane (coating) that can accept large movements between rock bolts; this is necessary so that the reinforced rock mass receives these loads. The most important parameters of any liner is to accept these loads in the following modes of failure which is flexure strength, shear strength and adhesion strength (see figure 1 shotcrete failure modes). MCS3 is far superior in these tests compared to wet shotcrete. (See table 2)
**Tensile Strength.** When adhesion strength between the rock and the liner is strong enough, the composite layer of rock / shotcrete provides the supporting mechanism. If the adhesion between the liner and the rock fails due to the loads on the rock, then the tensile strength will play the main supporting role by providing confinement to the fractured rock mass. MineCreteS3 has a much higher tensile strength than shotcrete in 24 hours and in 28 days as shown in figure 2.

<table>
<thead>
<tr>
<th>Test Type</th>
<th>Product</th>
<th>24 Hours</th>
<th>28 Days</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tensile Strength / Resistencia a la Tensión (material)</td>
<td>MineCrete S3</td>
<td>3.2 MPa</td>
<td>4.5 MPa</td>
</tr>
<tr>
<td>Shear Bond Strength / Resistencia a la Adherencia en Corte</td>
<td>40 MPa Shotcrete</td>
<td>0.25 MPa</td>
<td>0.68 MPa</td>
</tr>
<tr>
<td>Shear Strength (material) / Resistencia al corte (material)</td>
<td>MineCrete S3</td>
<td>5.3 MPa</td>
<td>7.4 MPa</td>
</tr>
<tr>
<td>Tensile Bond Strength / Resistencia a la adherencia en tracción</td>
<td>MineCrete S3</td>
<td>9.7 MPa</td>
<td>16.5 MPa</td>
</tr>
<tr>
<td>Energy Absorption / Absorción de Energía - EFNARC</td>
<td>MineCrete S3 @100mm @7.7 Kg or 50 mm polypropylene fibre / fibra polipropileno</td>
<td>915 Joules</td>
<td>1109 Joules</td>
</tr>
<tr>
<td>Compressive Strength / Resistencia a la Compresión Uniaxial</td>
<td>MineCrete S3 @2 hours / horas 3 MPa</td>
<td>18 MPa</td>
<td>36 MPa</td>
</tr>
<tr>
<td></td>
<td>40 MPa Shotcrete</td>
<td>4.5 MPa</td>
<td>40 MPa</td>
</tr>
</tbody>
</table>

Table 2. MCS3 Shotcrete Hybrid/ shotcrete conventional properties. (5)

**Shear Bond Strength.** To understand this fundamental property of interaction between the coating and the rock, it is important to know the concept given by Stacey (6): “key Block Interlock”. The effect of this mechanism is the preservation of the rock mass in a substantially unloosened condition. There are several sub-mechanisms involved in the promotion of key block interlock: the interlock that is promoted by the bonding of the shotcrete to the rock, and the tensile strength of the shotcrete, preventing shear on the interface and restricting block rotation (a); the development of shear strength on the interface between the shotcrete and the rock as a result of irregularity of the interface surface (b); the penetration of shotcrete material into joints and cracks (c), which will inhibit movement of blocks, which is particularly relevant in very high stress situations in which some loosening and stress fracturing will have taken place (d);
All of these sub-mechanisms described in the previous slides will limit the dilation of the rock mass. MineCreteS3, Shotcrete and other applied membranes (TSL) will be the membranes that will be appropriate to capitalize on these mechanisms, one better than the other. In contrast, it is unlikely that any of these mechanisms will develop with a wire mesh membrane, which will only serve as a net to catch loose fragments. It is only once sufficient bulking of the fragments has occurred to build up some support pressure that further fracture and failure development may be inhibited by wire mesh. Values developed by MCS3 in shear bond strength have no comparison with conventional shotcrete (Graphic 3).

Graph 3. Test of MCS3/Shotcrete in Shear Bond

(Shear Strength). This property is fundamental in the behaviour of liners at early ages. Good adhesion of the liner to the rock means that shear strength is the main failure mode of the liner. (See figure 1 and figure 4). The liner maintains the rock fragments, improving the stability of the rock mass, preventing its disintegration that leads to the formation of unstable blocks of greater dimensions. Shear strength depends on the strength of the concrete, the thickness of the same, the perimeter covering the lining and the size of the block or wedge to be contained.

Figure 3. Bulking of mesh wire.

“The shear strength of a fresh (immediately after it has been sprayed) shotcrete liner is the strength that it can resist subject to shear loading imposed by the rock mass during service. Within a few hours of spraying, shotcrete is quite capable of supporting a significant volume of unstable rock and that this volume or mass of rock may be calculated as a function of layer thickness and time after spraying. The minimum shear strength required for shotcrete to support blocks with 1 metre side lengths can be calculated from Villaescusa (7):”.

\[ \tau_s = \frac{F_T}{L_s \sqrt{2} \tau_s} \]  

Where:

\[ F_T = \text{total force to be resisted by the shotcrete in shear} = F_s + F_R \]  
\[ F_s = M_R g \] (MR is mass of rock and \( g \) = gravitational acceleration assumed to be 9.81 m/s\(^2\))  
\[ L_s = 4 \text{m (for 1 metre cube block)} \]  
\[ L_s = 3 \text{m (for equilateral tetrahedral block of rock with 1 metre side lengths)} \]
Gravitational acceleration $g$ is calculated using the formula $g = 9.81$ m/s$^2$.

Lining Density $\gamma$ is calculated using the formula $\gamma = 23,000$ N/m$^3$.

Average length of the shear surface (for equilateral tetrahedral block of rock with 1 metre side lengths) $L_s$ is calculated using the formula $L_s = 0.50$ m.

Lining Thickness $t_s$ is calculated using the formula $t_s = 0.050$ m for 0.05 m thickness and $t_s = 0.025$ m for 0.025 m thickness.

Shear Strength of Shotcrete $\tau_s$ is calculated using the formula $\tau_s = 130$ KPa for 0.05 m thickness and $\tau_s = 255$ KPa for 0.025 m thickness.

Compressive Strength of Shotcrete $V$ is calculated using the formula $V = 0.8$ MPa for 0.05 m thickness and $V = 1.6$ MPa for 0.025 m thickness.

Using the formula 2 for a shear strength of 0.8 MPa we will require a value in compression strength of 1.2 MPa for 50 mm (0.05 m) of thickness of the liner and for 25 mm (0.025 m) a value in compression strength will be required.

**Graph 5. Test of MCS3/Shotcrete in Shear Bond**

**Table 3. Calculation of the shear and compression strength of a liner of different thickness.**
of 2.3 MPa (in both cases it has been considered a Safety Factor of 1.5). The MCS3 hybrid shotcrete develops in just two hours more than 2.9 MPa in compression, as shown in Figure 4, which shows that this MCS3 Shotcrete Hybrid has the capacity to develop sufficient strength to hold a block of rock weighing 2,700 kilograms and its own weight when it reaches the resistance of 2.3 MPa in compression in a time of approximately less than 2 hours. The MCS3 hybrid shotcrete at two hours has enough consistency to be tested on the compression machine as a cube sample (Figure 4). MCS3 develops a shear strength of 5.3 MPa in 24 hours and 7.4 MPa in 24 hours, values far superior to conventional shotcrete, see Figure 5.

**Tensile Bond Strength.** Shotcrete is held in the rock by adhesion and strengthens it by avoiding relative movements in the shotcrete/rock interface and acts as a super membrane by providing a rigid retention element with substantial flexural capacity. In addition to the conventional strength parameters, such as the flexural strength, compression and tensile of shotcrete, the adhesion or strength of the shotcrete bond to the host rock must also be known in order to adequately determine the shotcrete’s ability to support the immediate ground near the surface of the mine opening.

The ability to determine the adhesion strength of shotcrete is a key component of the support design. A deeper understanding of the in-situ strength properties of sprayed concrete, in particular, the resistance of the adhesion of the shotcrete to the rock will lead to practical improvements mainly in quality, which will lead to avoid falling rocks and accidents to staff and teams. From graph 6 it is observed that MCS3 develops 1.59 MPa in 24 hours and 2.71 in 28 days. The conventional shotcrete develops average values of only 0.5 MPa as shown in table 4 made by Bernard.

![Graph 6. Test of MCS3/Shotcrete in Tensile -Bond](image)

### Table 7. Typical range for shotcrete bond strength with differing substrates*

<table>
<thead>
<tr>
<th>Interface</th>
<th>United States, MPa (psi)</th>
<th>Other Countries, MPa (psi)</th>
<th>Sweden, MPa (psi)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Shotcrete to shotcrete</td>
<td>nr</td>
<td>nr</td>
<td>1.0 (145)</td>
</tr>
<tr>
<td>Shotcrete to rock</td>
<td>nr</td>
<td>0.2-1.5 (29-218)</td>
<td>0.5 (73)</td>
</tr>
<tr>
<td>Shotcrete to concrete</td>
<td>0.69-1 (100-145)</td>
<td>0.5-3 (73-435)</td>
<td>1.5 (218)</td>
</tr>
</tbody>
</table>


Table 4. Typical values of adhesion bond of shotcrete.

### Energy Absorption.

According to the EFNARC tests carried out by Geopractica a independent testing facility in South Africa shows in Table 2, MCS3 develops 950 Joules of energy in just 24 hours and 1,109 Joules in 28 days, results obtained with the use of polypropylene fiber.

**MCS3 SHOTCRETE HYBRID APPLICATION**

In a test conducted in a mine in Peru, the use of 25 mm thickness was successfully tested instead of the 50 mm that would have had to be used with conventional shotcrete, in areas of poor quality ground (RMR 28-30), highly fractured with presence of faults with gouge, as shown in Figures 5 and 6.
MCS3 has been successfully used in mines in South Africa for two years with great success and has replaced the conventional shotcrete and is part of the support standard of these mines. MCS3 requires 448.2 Kilograms of its cement that includes all the additives required in a conventional shotcrete, plus polypropylene fiber. The recommended aggregate is of the "Grade 1" type that will allow a rebound percentage of less than 5% and a concrete with very low permeability and greater durability. (See table 5). MineCrete has a performance of 25 m2 / m3 for a thickness of 25 mm.

Table 5. Required quantities of the MCS3 hybrid shotcrete and conventional shotcrete.

<table>
<thead>
<tr>
<th>Descripción</th>
<th>Unidad</th>
<th>Shotcrete</th>
<th>MineCrete S3</th>
<th>Diferencia</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cemento</td>
<td>Kg/m³</td>
<td>450</td>
<td>448.2</td>
<td>-1.8</td>
</tr>
<tr>
<td>Fibra</td>
<td>Kg/m³</td>
<td>25</td>
<td>6.2</td>
<td>-18.8</td>
</tr>
<tr>
<td>Agregado</td>
<td>Kg/m³</td>
<td>1,600</td>
<td>1,210</td>
<td>-390.0</td>
</tr>
<tr>
<td>Sub Total</td>
<td>Kg/m³</td>
<td>2,075</td>
<td>1,664</td>
<td>-411</td>
</tr>
<tr>
<td>Plastificante</td>
<td>Kg/m³</td>
<td>3.3</td>
<td>-3.3</td>
<td></td>
</tr>
<tr>
<td>Acelerante</td>
<td>Kg/m³</td>
<td>25</td>
<td>-25.0</td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>Kg/m³</td>
<td>2,103</td>
<td>1,664</td>
<td>-439</td>
</tr>
</tbody>
</table>

Figures 7 and 8 show the manual spraying of MCS3 with very low levels of dust at the nozzle and only 4.5% rebound which allows for clear visibility of the rock mass which improves health and safety. Figure 9 shows the electrically driven MineCreter pump and mixer and electronic water dosing unit. MCS3 comes in bags of 28.4 kilograms (including fiber) and requires 3 bags of aggregate of 25 kilograms per bag and 12.4 litres of water which make a total of 115.8 kilograms per batch. In total, 16 batches are required for 1 m³.

Figure 6. Strongly fractured rocky mass (RMR 28-30) where 25 mm thickness of the MCS3 hybrid shotcrete was applied instead of 50mm of the conventional shotcrete.

Figure 7. MCS3 manual application in Peru. Note that the level of dust pollution is minimal and shows a low rebound for improved health and safety.

Figure 8. Manual application of MCS3 in Perú in a size excavation of 3.0 x 3.0 m.
Figure 9. Manual application of MCS3 in Perú with the mixing and pumping equipment (MineCreter Machine).

Figure 10. Final spraying of MCS3 with 25mm (1”) thickness.

Figure 11. Final spraying of MCS3 with 25mm (1”) thickness.

Figure 12. Drilling of holes for bolting through 25 mm (1”) thickness of the MCS3.

Figure 13. Drilling of holes for bolting through 25 mm (1”) thickness of the MCS3. No cracking was observed.

Figure 14. Drilling of holes for bolting through 25 mm (1”) thickness of the MCS3. No cracking was observed.

Photos 10 and 11 show the final spraying of the MCS3. After two hours of setting MCS3 has achieved enough strength to drill the holes for the installation of the rock bolts as shown in
Figure 12. In Figure 13 and 14 it is observed that there is no cracking in the MCS3 Hybrid Shotcrete.

In the case of mechanized spraying, all robotic machines currently used in underground mining operations are compatible with MCS3. In this case, 25 mm thickness of the MCS3 Hybrid shotcrete, was sprayed in a poor quality ground (RMR 30-33) instead of 50 mm of conventional shotcrete. The bolts were drilled only 2.5 hours after being sprayed without any inconvenience or cracking, bolt plate did not penetrate into the MCS3 because of the fast setting. (See photo 17 and 18).

Figure 15. Spraying of MCS3 using a robotic machine in Perú.

Figure 16. Final spraying of MCS3 in an excavation of 4.5 x 4.5 m.

Figure 17. Drilling of hole with a bolter machine through 25 mm (1”) thickness of the MCS3

Volumetric Mixers. The MCS3 Shotcrete Hybrid has a very fast setting time (30 - 40 minutes), therefore, the product is mixed on site. To solve this problem, a new technology for underground mining has been introduced. The "Volumetric mixer, “VM”. This new equipment has individual compartments for transporting the required dry materials such as MCS3 cement, aggregate, fibres and water. Another additional advantage that allows you to mix the MCS3 at your required location underground. The VM has a electronic weighing system that will print out the individual amounts of MCS3 cement, aggregate, fibre and water used. Allowing you to have exact quality control of your mix design, eliminating any chance of wasted product. This equipment is also a hybrid between a batching plant and a transport mixer (two in one), thus eliminating the need to have fixed batching plants and aggie cars. With the VM you can store your raw materials underground close to your working areas. This will save a lot of time of having to go back to the batch plant to reload. The VM

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comes in different sizes, which can hold from 5m³ up to 9.5m³.

Figure 19 shows a VM which can hold 5.5 m³ of MCS3 that can drive in an excavation of 3.5 x 3.5m. The Equipment can be supplied for most excavation sizes.

Figure 19. Volumetric Mixer of 5.5 m³ for excavations of 3.5 x 3.5 m.

Figure 20. Volumetric Mixer feeding MCS3 into a robotic sprayer.

Figure 20. Volumetric Mixer feeding MCS3 into a robotic sprayer.

PRODUCTION RATES
Taking into consideration of all the above information, it is possible to reduce the thickness of the shotcrete with MCS3. For example, if a mine currently sprays 1,500 m³ of shotcrete per month, with a rebound of 15% and a rehabilitation of 15%, now with MCS3 Shotcrete Hybrid only 564 m³ will be required, with a low rebound of 5%. In table 6, the required quantities are detailed.

Table 6. Production rates and monthly quantities required.

Table 7. Increase in development and blasts with the use of MCS3.

With the use of MCS3, there will be savings in the use of 936 m³ of shotcrete in a monthly basis. This saving in time will allow to increase the number of blasts. For example, an excavation size of 3.5 x 3.5 m and the saving in spraying time of 936m³, ore and waste rock development could be increased by 105 meters per month, also a reduction in re-entry time after spraying from 3 to 2 hours, see table 7.

For the same example of 1,500 m³ per month (see table 8), the quantity of aggie cars required decreases from 4 to 2 VM (see table 9).
Cuadro 8. Monthly consumption required.

Table 9. Volumetric Mixers required.

The instillation cost of shotcrete batching plant, silo and civil works with four aggie cars, can cost up to $1,780,000.00 while the MCS3 would only need two VM and 2 backhoe machines at a total cost of $760,000.00 with a saving of over a million dollars. See table 10.

Table 10. Capital investment to implement conventional shotcrete and MCS3.

CONCLUSIONS

- MCS3 Hybrid Shotcrete has the advantages of the TSL in tensile, shear, tensile bond and shear bond, compression strength and energy absorption of conventional shotcrete, this allows us to reduce the thickness of shotcrete by 50%.
- This MCS3 Shotcrete hybrid is a new liner where NO additives are needed, it’s only necessary to add aggregate, fibre and water.
- MCS3 is a unique concrete formula that has taken the concept of passive support to an "active accelerated support" giving you structural support and also sealing the fractures and consolidating the rock mass reducing the movement of the key blocks and reducing weathering and oxidation, a process known as "Key Block Interlocking ".
- Due to reduced thicknesses and minimised rebound of 4.5%, 1m3 of MCS3 can cover an area of 25m2 at a thickness of 25 mm 1”.
- With the use of this MCS3 it is possible to increase your production rates, by reducing your amount of m3 pump per shift. This will make it possible to increase blasting cycles and ore production increasing overall profitability to the mine.
- Due to fast setting of MCS3 in just two hours it is possible to re-enter the working area that has been sprayed and continue installing the primary support with no issues.
- With the application of MCS3 there are very low levels of dust pollution helping with health and safety underground, and are unmatched by conventional dry or wet shotcrete.
- MCS3 does not shrink insuring that the bond to the rock surface will stay intact. As opposed to shotcrete that has up to 3% shrinkage and for that reason will de-bond from the rock surface.
- Due to its fast setting speed, it is required to mix the MCS3 components in the working area to be sprayed and supported, this involves using a MineCreter or VM and robotic sprayer. MCS3 will not require the use of fixed shotcrete batching plants on surface or underground and the use of Barrel mixer trucks (aggie cars) will no longer be required.
- MCS3 can be used in the mining and civil engineering industries.
- MCS3 is non-flammable and non-toxic and does not contain any toxic accelerators that generate burns to workers in contact with the skin and / or inhalation. It is how ever required to use the same personal protection equipment used with conventional shotcrete.
• MCS3 does not interfere with the metallurgical recovery process or getting the material to the metallurgical processing plant.
• The amount of equipment required with the MCS3 is less than that required with the use of shotcrete, and since no concrete plants are required, the capital costs are substantially less.

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