RockWeb – An innovative TSL technology for today's mining environments and the next generation of hard rock mine operations

T. Macpherson
Spray On Plastics Ltd, Rockwood, Ontario, Canada

ABSTRACT: Drawing on past research experience with sprayable polymer mine support agents (TSLs), Spray On Plastics Ltd. has developed a TSL ground support system called RockWeb. Using a relatively new polyurea polymer technology, RockWeb has been engineered to solve problems encountered underground with polyurethane liners by incorporating rapid curing, moisture insensitivity and superior physical performance.

RockWeb possesses a unique, patented ability to be sprayed in a "cobweb" like consistency allowing the applicator to span fissures in the rock, ensuring no initial defects in the liner, and maintaining design thickness over highly irregular surfaces. This ability, coupled with the high strength and elasticity of polyurea, allows RockWeb to mitigate rock movement through yielding, while maintaining intimate surface confinement.

RockWeb provides reduction in logistics through the transport of 1/25 of the material quantities required for shotcrete, rapid deployment rates of as little as 30 minutes per round, and immediate return to the work area.

This paper will discuss the technology and advantages of RockWeb as well as opportunities for overall mining cycle cost reduction. The safety benefits, as well as health and environmental considerations regarding application of isocyanate-based liners will also be discussed.

1 BACKGROUND

Spray On Plastics Ltd. is a manufacturer and applicator of hot-spray polymer linings for many industries including finishing, industrial containment, concrete fire protection and mining.

In the early nineties, Spray On Plastics, was hired as the contractor to the first North American TSL: a polyurethane-based, elastomer. For a period of five years, the company served as applicators of the Mineguard^{TM} TSL. Many underground applications were undertaken at various mines throughout Canada, including the Sudbury Neutrino Observatory at INCO's Creighton Mine.

It became evident in those early days that the traditional polyurethane systems were not going to work. The liquids were sprayed in a fashion similar to paint, coating either side of a crack in the rock, but failing to bind the rocks together. In order to obtain complete coverage, the product had to be applied well above design thickness. Furthermore when applied to the back, the hot liquids would drip from the back, wasting more material and often landing on the applicator. When applied in damp areas the urethanes would react with water causing them to foam and become weak.

A few years passed, and Spray On Plastics began to formulate and blend polymer systems. This led to the movement away from urethanes, to a new chemistry called polyurea. Polyurea elastomers are stronger than polyurethanes, with better resistance to tearing, heat and chemical degradation. They also are significantly less sensitive to moisture during spraying allowing them to maintain their properties when applied in damp areas, rather than foaming as occurs in polyurethanes.

Development of polyurea systems led to a serendipitous discovery. While attempting to create a highly rigid coating system that could compete with fibreglass, a strange characteristic was stumbled upon. With the use of a new raw material, it was discovered that the polyurea could be sprayed in a form resembling spider webs. (Figure 1) When the company president saw this it reminded him of the problem he had encountered in the mines. The "webs" could be sprayed between large gaps placed between boards in the spray booth. Further investigation of this unique property led to refinement of the webs and in the late 90's RockWeb was born.

Figure 1: RockWeb sprayed in-booth, 4mm thick across a gap of 80mm.

2 TECHNOLOGY

RockWeb is a 3 part polyurea composed of MDI isocyanate (A component, liquid), amine resin (B component, liquid) and fire retardant (C component, powder). A and B components are drawn from 200 L drums using transfer pumps and conveyed to the proportioner.

The *proportioner* is a fixed-ratio displacement pump which meters the liquid materials at a 1:1 ratio and brings them up to a pressure of about 200 bar. (Figure 2) The materials are then passed through a heater which warms the chemicals to precise temperatures, after which they are passed through heated hoses to the spray gun.

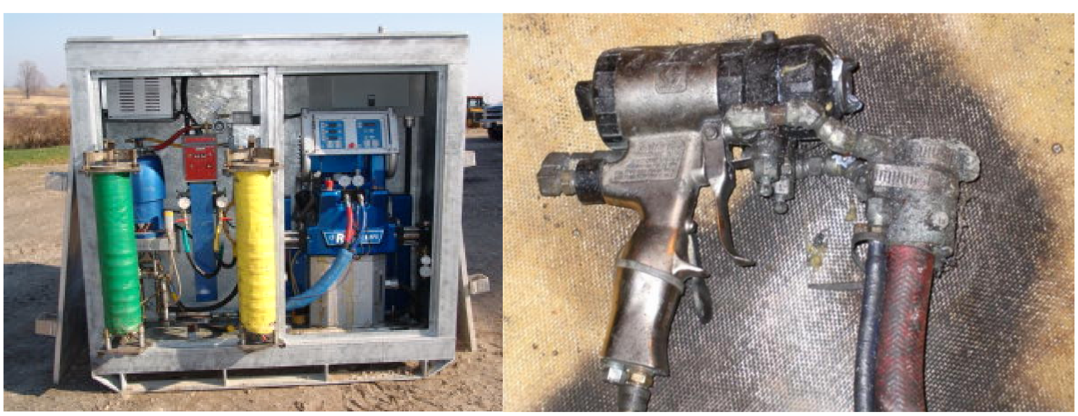

Figure 2. RockWeb proportioners and spray gun

The spray gun is an *impingement mix* type. This means that the chemicals are mixed together when 2 high pressure streams collide at high velocity inside the *mixing chamber* and are then passed out through the open barrel of the chamber. The higher the pressure is the better the mixing.

Once the polymer is mixed, the C component is blown into the stream of the reacting polymer to create a flame-reactive composite. This composite has displayed the best flame spread ratings of any polyurea. When touched by a flame, the surface of the composite expands to nearly 100 times its volume, shielding the underlying composite from heat.

Prior to the application of RockWeb, a primer is sprayed onto the rock surface using identical equipment as RockWeb, only without the C component. The purpose of the primer system is to promote adhesion to the rock by displacing moisture and encapsulating dust on the rock surface, and by penetrating into the rock itself, thereby increasing the cohesive strength at the rock/TSL interface. Average adhesion values in excess of 2 MPa have been recorded and are high relative to other TSL materials, and meet or exceed that between shotcrete and rock. (Ozturk & Tannant, 2004)

RockWeb is an RHSF (reactive, high strength, flexible) TSL. (Spearing, 2003) It is solid in less than 10 seconds, reaches over 1 MPa tensile in minutes, has 75% of its UTS and bond strength in one hour, and is fully cured in 24 hours. Cure time is only marginally affected by temperature, and there are no solvents or water to evaporate. RockWeb's UTS is 13 MPa, and it can be stretched up to 100% elongation. These properties provide physical performance untouchable by non-reactive latex/cementitious TSLs.

3 FEATURES AND BENEFITS

3.1 *Webbing*

Defects in a TSL are of major concern. TSLs are effective in part because of their ability to absorb displacement. (Swan et al. 2006) If the liner is created with a pre-existing breach, when displaced, it will fail at that breach. The problem of initial defects is exacerbated as we move toward automation.

The "webbing" feature of RockWeb provides many advantages. It allows applicators to obtain full coverage of the rock surface in a single pass. Since they are already semi-rigid as they leave the gun nozzle, the webs can stick to outcroppings and "flip" around the obstruction effectively coating the areas not easily visible. Cracks are penetrated and bridged by the mat of material minimizing the risk of defects in the liner.

TSLs are also effective because of their ability to bond together foliations in the rock. Displacement of the rock occurs in part because of the unraveling of the outermost layers. Failure is accelerated as the smaller pieces of rock fall out of the joints between the larger blocks. As the layers begin to open up, they lose the support provided by their adjacent layers. By bonding together the foliations as early as possible, the opportunity for relative movement between foliations at the surface of the excavation is prevented, thereby maintaining the "keystone" effect and allowing the surface of the rock to support itself, rather than holding back a bag of loose that simply becomes "looser".

3.2 *Other Benefits*

RockWeb presents opportunities for short and long-term cost benefits. One pair of drums (A & B component), two 20 kg bags of C component, and two pails of primer are referred to as a supply pack. A supply pack contains enough material to provide 125 m^2 of ground support, approximately equal to two average rounds. The same two rounds could require as much as 25 skids of dry shotcrete. From this, one can easily see the logistical savings in the caging and transport of materials.

From a time perspective, one of the rounds mentioned above can be sprayed in as little as 30 minutes. Large infrastructure jobs have proven application rates of up to 300m^2 per shift. Bolting can be completed immediately after spraying, with no harm to the liner, or the bolting equipment. Since no screen is being installed, a bolting pattern suited to the ground conditions may be used instead of the pattern needed to pin up screen. Bolt consumption may in turn be reduced.

Rehabilitation is another source of the hidden costs of support systems. When subjected to displacement, shotcrete cracks and spalls and mesh can deform, break welds or tear. RockWeb will stretch when displaced, extending the amount of time for failure to occur well beyond that of traditional support media. If tearing occurs, rehabilitation involves washing, re-priming and re-spraying. No new bolts should be required.

Mesh also corrodes, especially where acidic species are present in the air and water. RockWeb will not only stand up to chemical attack, but can help to prevent the formation of the acid compounds by sealing sulphides and carbonates away from contact with air and water.

Dynamic blast testing by Queens University (Archibald & Katsabanis 2005) of several conventional, TSL and combined ground support systems has demonstrated RockWeb's ability to mitigate ground falls while sustaining minimal damage. Under these tests, a 4m x 5m patch of RockWeb was subjected to bursting ground velocities up to 8 m/s. Minimal tearing was observed in the area surrounding the blast hole with an average of 3 cracks at 18 cm length. (Figure 3) Most notably, where other systems tore, rock fragments were ejected. The rock supported with RockWeb, though destroyed below the surface, was contained by the liner. Where the liner did break, the rock fragments remained bonded to the liner by a "hinge" of plastic. The majority of the damage to the liner was caused by stemming being ejected from the blast hole.

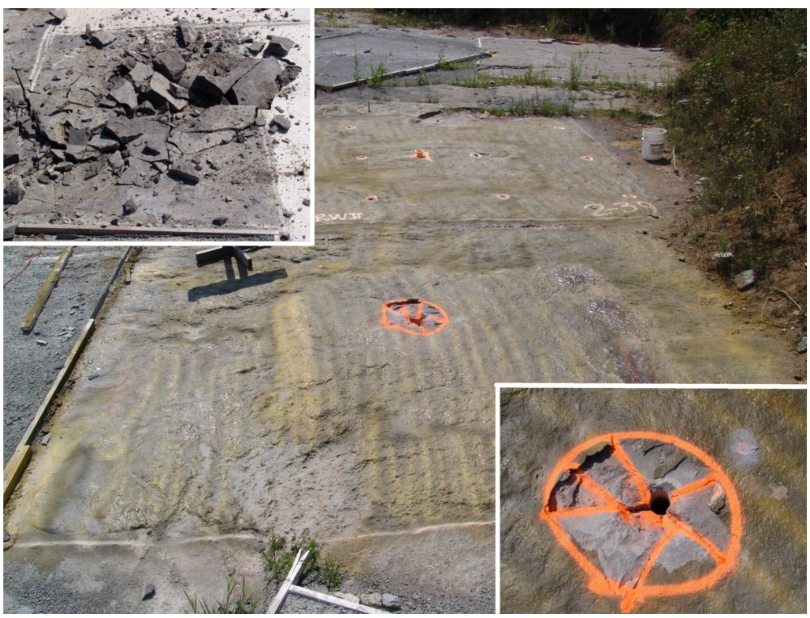

Figure 3. Blast damage to unsupported and RockWeb supported rock

4 HEALTH AND ENVIRONMENT

4.1 *Isocyanates*

Diisocyanates are compounds used to produce polyurethanes and polyureas for many different applications and products. They are not, nor do they contain cyanides. Component A of RockWeb is mainly composed of a chemical called diphenylmethane 4,4' diisocyanate (MDI). In most jurisdictions, diisocyanates are designated substances, meaning there are specific regulations that must be adhered to during their use. Most jurisdictions have codes of practice and allowable concentrations that are identical.

In Ontario, the regulation is O. Reg. 842, Designated Substances, Isocyanates. The rules outlined in this regulation are similar to those for silica, also a designated substance, which many mines are already used to dealing with. This regulation states that exposure of a worker to MDI must be below time-weighted average concentrations of 5 ppb (50 $\mu g/m^3$) MDI for an 8 hour shift, and below 20 ppb (200 $\mu g/m^3$) for any length of time. Within these limits, workers may operate without any respiratory protection. The effect of intense acute or chronic exposure to isocyanates above these levels is respiratory sensitization also known as occupational asthma, with often irreversible damage to the respiratory system.

To date, all underground applications of RockWeb have been monitored for MDI. Independent monitoring has been conducted by several mines, including NIOSH's Lake Lynn Laboratory. (Valoski et al. 2002) When analyzed using a variety of analytical methods, few samples contained quantifiable levels of MDI. Of those which did contain MDI, airborne concentrations were well within acceptable limits.

Real time monitoring for MDI is always conducted by applicators during spray operations. The monitor draws air at a calibrated rate through a paper tape which discolours in the presence of isocyanates. The discoloration is measured spectrophotometricly (using reflected light) and correlated automatically to calibration data, then a concentration is displayed on the monitors LCD readout. The monitor is sensitive to 1 ppb, with an accuracy of +/- 20%. It is also sensitive to the presence of contaminants, especially dust, in the air. These contaminants lead to false positive results as they scatter and absorb light. Though not an analytical quality tool the monitor possesses two useful characteristics; it gives real time results instead of waiting weeks for a lab's response, and it will never give false negative readings.

Encouraging monitoring results do not however negate the need for personal protective equipment. Though many respiratory protection codes require supplied air respirators at any concentration, Spray On Plastics recommends the use of cartridge respirators with prefilters. These have been shown to be 99.99% efficient in the removal of MDI from air at concentrations of 1200 $\mu g/m^3$ of air. (Spence et al. 1997) This is 24 times the time weighted average exposure that is allowed. Spray applicators wear full-face respirators, and support crew wear half-face pieces. Any residual isocyanate that may be in the air leaving the work area is processed through a fine mist water curtain. The isocyanates react with the water to form harmless polyurea solids, and the air is returned to the mine.

4.2 *Waste Disposal/Spill*

The chemical components of RockWeb are transported underground in double-walled, insulated steel containers. (Figure 4) Each container contains a complete supply pack of materials. The containers are reasonably puncture proof and guarantee safe handling of chemicals. To date, there have been no spills of any RockWeb components on any sites.

Figure 4. RockWeb supply pack in double walled container

In the unlikely event of a spill, isocyanate and resin components can both be absorbed with waste muck. In the case of isocyanate, when mixed with moist muck and left in open containers the isocyanate will be neutralized by water and harden. The resulting solid can be disposed of as normal solid waste.

Reacted RockWeb poses no hazard to handlers. It can be disposed of as normal solid waste.

5 PROJECTS

5.1 *Underground Infrastructure Protection*

RockWeb was applied over approximately 2300 m^2 of shotcrete in the back of newly constructed large infrastructure rooms in two mines in the province of Quebec. (Figure 5) The rooms contain hoisting equipment for a winze in the first of the mines, and grizzly and jaw crushing equipment in the second. The purpose of using RockWeb was to protect the shotcrete from cracking, and to retain any pieces of the shotcrete that may have come loose. The rooms ranged in height from 12 to 25 meters. Falling debris in these areas could cause injury to personnel, and damage to the infrastructure, especially the cables in the case of the winze.

Figure 5. RockWeb applied to shotcrete over a winze sheave deck. Obstructions are easily sprayed around with little mess or overspray

In the past, common practice would have been to use chain link for this purpose. Given the height of the rooms, chain link would have been difficult to install from the telescopic manlift needed to reach the back, requiring many return trips to the ground for materials. Chan link also would not have been able to contain any tiny fragments that worked loose, nor would it have been able to provide the surface confinement that prevents the shotcrete from breaking. The installation of RockWeb was easily and quickly completed, as the spray hoses reached over 160 feet from the pumping equipment.

5.2 *Shaft Repair*

A mine in New Brunswick was experiencing problems with a section of shaft that was converging slightly due to moisture swelling of a graphite zone passing through the shaft. The concrete liner had broken in a 3 m wedge along one side of the shaft. Due to the tight tolerances between the shaft collar and the cage, the use of shotcrete was not an option. The damage had twice been repaired with a non-reactive, latex/cementitious TSL. Both times the TSL lost its bond around the edges and the wedge began to work loose again.

The existing TSL was removed, and RockWeb was sprayed at a thickness of approximately 10mm over the entire wedge, and extended about 60 cm out onto the collar. Because RockWeb cures instantly, a few 25mm holes were easily left in the collar to allow water pressure on the wedge to be relieved. After one year in service, no debonding of the liner was noted.

5.3 *Haulage Drift Rehabilitation*

A mine in the Hemlo region of Ontario had planned the rehabilitation of an aging main haulage drift, now used only for egress. Past ground support had included a variety of systems mesh, mechanical bolts, rebars and steel straps as well as shotcrete. Over time, all had degraded and failed. The previous ground support was removed where possible, and a nominal thickness of 4mm of RockWeb was applied to a 125 m long section of the 5m x 5m drift.

The application took a little over 3 shifts. The most stringent health and safety policies were applied, and the application was overseen by an Ontario Ministry of Labour inspector. At the end of the job, MOL's only objection was that the supply pack containers had no external labels on them.

After 2 years in service the shift boss who works in that area describes the RockWeb as looking "like the day it was sprayed".

6 CONCLUSIONS

Thanks to the participation of many members of the mining industry, applied and academic, the ground work for TSLs has been laid. Though widespread acceptance of TSLs has yet to occur, years of research and development coupled with recent successes in field application have proven that RockWeb can safely provide the support parameters necessary to increase the longevity of ground support, and of the people working under it.

With increasing mining depth, conventional support techniques are becoming less able to withstand the demands placed upon them. As the need for high speed, flexible support increases, the gap between conventional technology and the needs of rock mechanics widens. RockWeb stands prepared to bridge this gap.

REFERENCES

Archibald, J.F. & Katsabanis, P.D. 2005. Ground Fall Mitigation Capability and
Enhanced Testing for Rockburst Susceptibility of Rock Liners*, WSIB Project #03 010, Submitted to the Workplace Safety and Insurance Board of Ontario, October 30, 2005*

Ozturk, H. & Tannant, D.D. 2004. Effect of Environmental Conditions and Rock Properties
on Adhesive Bond of Thin Spray-on Liners, *CIM Mining Industry Conference & Exhibition, Edmonton 2004*

Spearing, A.J.S. 2003. Proposed Thin Support Liner definitions, performance categories and test methods, *Surface Support Liners, Proc. 3rd Intern. Seminar, Quebec City, 25-27 August, 2003*

Spence, M.W., Landry, T.D. & Huff, D.W., 1997. Evaluation of the Effectiveness of Air-Purifying Respirator Cartridges in Removing MDI Aerosols from Air, Dow Chemical Company, published on OSHA website: http://www.osha.gov/SLTC/isocyanates/mdi/mdi.html

Swan, G., Carlisle, S., Maybee, G., Pritchard, C., Sampson-Forsythe, A., Simser, B. & Counter, D. 2006. Ground Support Systems for High Stress Conditions: Theory vs. Experience, *Deep and High Stress Mining, Proc. 3rd Intern. Seminar, Quebec City, 2-4 October, 2006*

Valoski, M.P., Arnold, E.J. & Mewa, P.T. 2002. Industrial Hygiene Field Investigation: RockWeb Mine Roof and Rib Support Sealant, *Investigative Report PP-001-030,* NIOSH Lake Lynn Laboratory, 4 October, 2002