SPRAYED CONCRETE SYSTEMS FOR PRESENT AND FUTURE: LOGISTICS AND APPLICATION

Michael Rispin, P.Eng. – Managing Director, Normet Americas - NAFTA Region – Union Grove, WI, USA

Tom Melbye – Chief Operating Officer – Normet International – Baar, Switzerland

Richard Kraft – National Sales Manager – Normet Americas – Portland, OR, USA

INTRODUCTION

The "modern era" of sprayed concrete (wet mix shotcrete) application in underground mines arguably began around 1990. At that time, concrete technology significantly increased its pace of development and the combination of superplasticizer, hydration control and set accelerator advancements allowed high quality spray application to be effected through the robotic equipment of the time.

Over the course of the next two decades, ongoing progression with chemistry accompanied by development in concrete pump, spray boom and accelerator dosing system technology, as well as the global heightening of the awareness of the key principles of a sprayed concrete program, contributed to the proliferation of the ground support method to where today, over 60% of sprayed concrete in underground mining is done via the wet method.

The benefits of a quality sprayed concrete program and its advantages as a ground support method are well documented.

- Average rate of application in a practical sense is 12 m^3 / hr
- Typical development rounds can be sprayed in 25 mins
- Rebound is low, typically in the order 5-10% for an experienced crew
- Quality control (water/cement ratio) of the concrete is managed at the batch plant, not at the nozzle as with the dry method
- Very low dust levels generated

Compared to how sprayed concrete may have been viewed in the early 90's, it is now a favored support method. As a result, a new mine of any significant size typically looks first at sprayed concrete as a means of rapidly applying durable, surface support as part of its ground control philosophy.

STATE-OF-THE-ART

Sprayed concrete, while sometimes thought of only in terms of the act of spraying itself, is in reality a significantly more detailed process. Accordingly, each of its aspects must be understood and implemented, not only individually but in consideration of the interdependent system. A “holistic” approach, as in Figure 1, is therefore recommended.

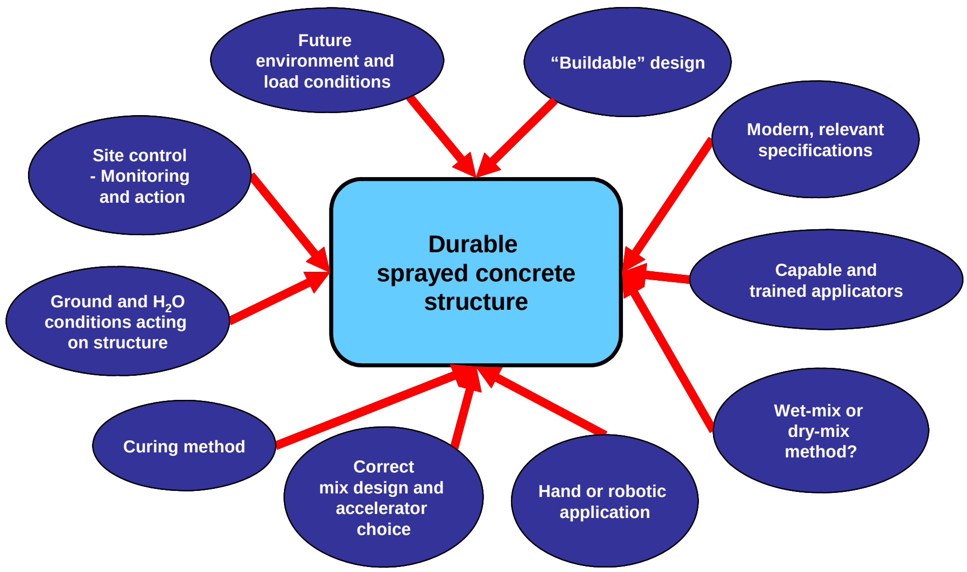

Figure 1 – A holistic approach to durable sprayed concrete

Ground support design, concrete mix, raw material sourcing, chemistry, logistics planning, equipment selection, operator training, quality assurance & control, and curing are all aspects to be reckoned with. Once a system is in place, from an ongoing, sourced component perspective, the three integral components are shown in Figure 2.

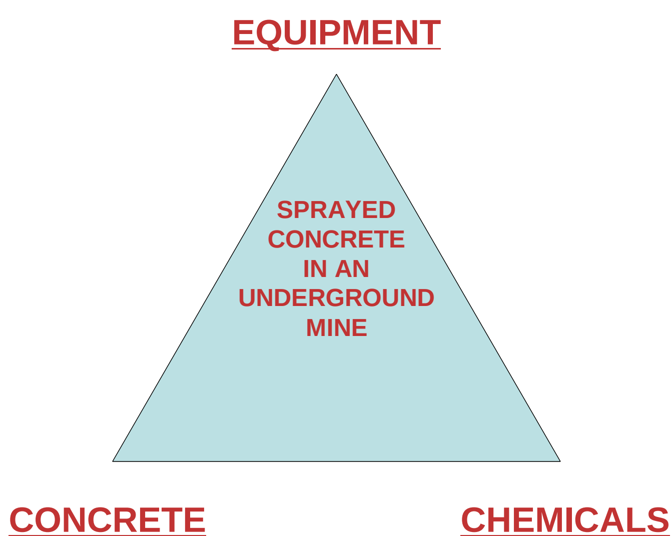

Figure 2 – Three integral components underground

These are "table stakes" and must be soundly designed and operated, supervised and supported on a daily basis.

Concrete may be manufactured on site by the mining operation itself, contracted on-site by a reputable manufacturer, or transported to site from a remote source. Mix design, raw material sourcing, flexible delivery capability, and QA/QC are key components to the performance specification, which is typically expressed in terms of temperature, consistency and strength development targets.

Chemicals today involve the application of hyperplasticizers in the mix to offer workability while ensuring optimum strength development at a lower water/cement ratio, hydration control agents in the mix to preserve freshness and "non setting" of the concrete for a specified time period (a key to logistics), and an alkali free set accelerator (tailored to the specific cement chemistry in the mix) applied at the spray nozzle to make adhesion, thickness buildup and early strength development possible.

The equipment typically involves concrete transportation vehicles and robotic sprayers, and these will be discussed in greater detail in subsequent sections of the paper. However, as important to the sprayed concrete system as selecting the right equipment, choice of supplier must also consider heavily up-front the ongoing aspects of "Life Time Care":

- Commissioning
- OEM spare parts
- Preventive maintenance
- Maintenance and operator training
- Overhaul and/or rebuild

LOGISTICS – THE "MAKE OR BREAK" OF THE SYSTEM

If one assumes that the "table stakes" are taken care of in an assiduous manner, then the issue of whether concrete can be sprayed into place and will perform as advertised is not in question.

The true benefits in efficiency and safety arise out of the design of the logistics: getting the concrete from point of manufacture to the working face as effectively as possible.

For new mines, given the propensity of operations to look first at sprayed concrete as a component of their ground support system, designing the infrastructure to accommodate the transfer system is a relatively uncomplicated and well understood exercise, regardless of the dimensions and orientation of the orebody. Ideally, a separate system is put in place which allows the transfer of the material without burdening the shaft or unduly clogging up vast sections of a ramp system. Figure 3 shows a typical flowchart of a sprayed concrete logistics system.

Concrete: Mix Design/Chemicals/Manufacture

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Surface Transport

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Vertical Logistics: Borehole, Slickline or Ramp

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Underground reception

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Transportation: Agitators, Transmixers

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Sprayer + Operator

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In-situ Sprayed Concrete

Figure 3 – Typical Sprayed Concrete Logistics System

For an existing mine, retrofitting a transfer system can be more challenging but certainly not impossible nor ineffective, given the number of operations that have successfully accomplished it.

The logistics system involves a combination of fixed installation and mobile equipment and, depending upon the needs of the operation, there exist a variety of permutations and combinations to suit the purpose. For flatter, shallower orebodies with ramp access, specifically designed transmixers are almost exclusively the means of choice. For deeper and more steeply dipping orebodies, a dedicated borehole (or slickline) – or potentially one shared with backfill transfer – is the preferred infrastructure. For this, a suitable energy dissipating device must be installed at the bottom of the borehole to receive the concrete. This is shown in Figure 4.

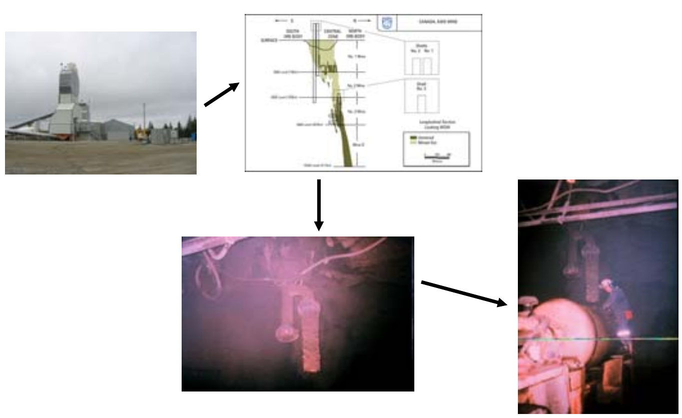

Figure 4 – From Concrete Plant to Underground

Transmixers

Integral to every sprayed concrete logistics system, transmixers are the mobile element for horizontal and, in the cases of ramp access, vertical transportation. Two types of underground transmixers are shown in Figure 5.

Figure 5 – Typical Transmixer Types

The key element to transmixer selection is design-for-purpose:

- Concrete payload capacity matched to development heading requirement
- Drum designed for limited height
- Agitator design if additive remixing is required
- Tramming speed
- Axle and braking for ramp worst case scenario
- Drum discharge matched to sprayer concrete pump hopper

While the above are basic in equipment selection, care must still be taken in specification.

In some jurisdictions of the globe, “road type” concrete mixers have been used underground where permitted by easy access but recent safety concerns, including injuries and equipment write-off, are such that the authors recommend strongly against this. Mineworthy transmixers are the only choice.

KEYS TO APPLICATION

The spraying of the concrete, or the “business end” of the process, involves two components: the mechanical sprayer and the operator. While operator training is a must - as with all types of underground mobile equipment – the most significant key to application is the proper equipment selection.

Mechanized Sprayer

Not all sprayers are created equally and there exist many manufacturers, model types and configurations for the mine operator or contractor to choose from. Figure 6 shows a state-of-the-art mining sprayer.

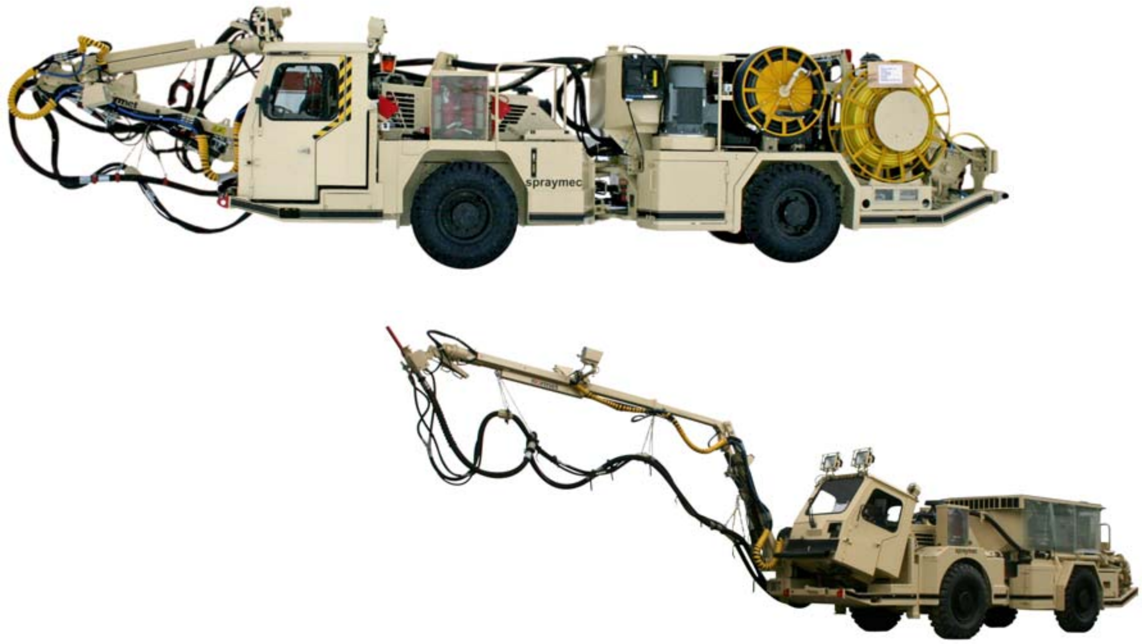

Figure 6 – Mechanized concrete sprayer for mining applications

The carrier, engine and power pack must be selected based on payload, tramming capabilities, emission requirements, services (power, air, water) availability, as well as all the aspects of mechanical care as described earlier in this paper. These are important considerations for the operator and maintenance team which will keep the units up and producing.

From there, mechanized sprayers differentiate by purpose from other mine vehicles with the need for careful selection of concrete pump, spray boom, accelerator dosing system and potentially a compressor, all key factors for the consistent spraying of quality concrete.

1. Concrete pump
    - Filling rate
    - Low pulsation
    - Simplicity and durability
2. Accelerator dosing system
    - Integrated to concrete flow
    - Simplicity and ease of troubleshooting

3. Spray boom
    - Durability and stability
    - Maneuverability
    - Lighting

A critically important factor often overlooked with lower end sprayer technology is that of pulsation of the concrete pump (typically dual cylinder positive displacement): this must be minimized. The pump must be designed to effectively fill the cylinders at a good rate and transfer output from one cylinder to the other as seamlessly as possible. Minimizing pulsation allows for consistency of flow and application, minimizes layering in the applied concrete, maximizes consistency of accelerator dosing, reduces “fallouts” during application and lessens wear and tear on the piece of equipment. A sub-standard concrete pump can result in pronounced layering as shown in Figure 7.

Figure 7 – Pump pulsation can cause pronounced concrete layering

The dosing system must be matched to the concrete pump, integrated to the stream of concrete being sprayed, and properly designed for introduction of the alkali free accelerator at the spray nozzle.

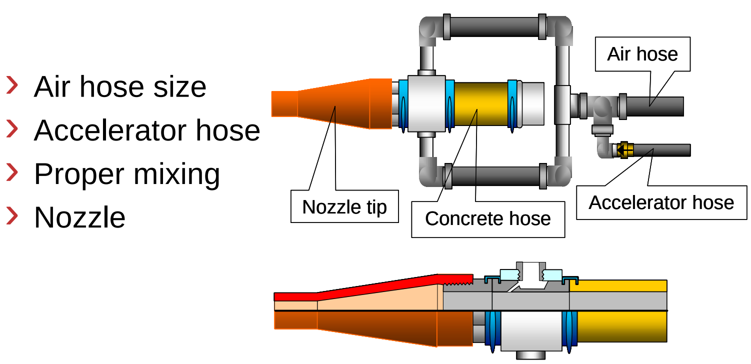

Figure 8 – Accelerator / nozzle set-up

A proper nozzle set-up for alkali free accelerator is shown in Figure 8.

Mines often choose to supply air from their own piped in system. Provided that adequate pressure and volume can be assured, this poses no problem. However, should there be any concern, an on-board compressor may be included on the sprayer so that the recommended parameters of 6-7 bar at 10-12 m3 / min are obtained.

During the actual spray operation, the equipment must allow for a proper operator vantage point either from the cab or external to it, supplemented by either a hard-wired or radio remote. In this way, substrate preparation and concrete spraying can be accomplished with a high degree of quality.

DEBUNKING MYTHS

Process knowledge is critical and, for inexperienced operations, your equipment supplier can provide a wealth of knowledge from experienced, qualified personnel. Of course, with the growth in sprayed concrete in recent years, the overall level of expertise in the industry has improved substantially. Nevertheless, the authors still encounter “myths” or misconceptions which have pervaded the industry. A selection is addressed in brief here.

“Sprayed concrete is expensive vs. bolts and mesh.” While this may be true from a pure materials comparison perspective, it is the overall in-situ cost over the lifetime of the operation where sprayed concrete is advantageous. Logistics, speed of application and reduced rehabilitation must be factored into the analysis.

“You can’t drop concrete more than 750m.” In fact, concrete is regularly dropped down boreholes in excess of 2000m in length, with maximum known lengths in excess of 2500m having been achieved. Further, with a properly designed mix, borehole and procedures, there is no known limit to the depth to which concrete can be dropped.

“Sprayed Concrete isn’t ductile.” When taken out of context, this is a truism. However, the material itself can have significantly greater ductility imparted to it with the addition of reinforcement (ie. fibres). Moreover, the ductility of the material in isolation is not nearly as important as its performance as part of a properly designed system (ie. in conjunction with bolts, and in some cases strapping or lacing). In this way, sprayed concrete can and has functioned in high stress (quasi-static or dynamic) situations.

“Mesh is better than fibres.” Fiber reinforcement, particularly with the recent wave of high tech macrosynthetics available, has proven to be clearly advantageous vs. mesh. The ability to dose the fibres directly into the concrete mix (a “one pass” system), their dispersion through the concrete matrix, and residual toughness with displacement combine to offer a most compelling system.

WHAT DOES THE FUTURE HOLD?

All the aspects of a high quality sprayed concrete program as discussed prior in this paper position a mine operator with a state-of-the-art present and a foundation for the future. As to what developments will drive sprayed concrete further, some elements are closer to fruition than others. As mines trend more to the underground, and to greater depths in more challenging conditions, and as the need for rapid development to bring mines into production faster in these challenging economic times increases, some items must be looked at more closely than others.

The ability to spray concrete to a specified thickness is very important; too little and you have a potentially underperforming ground support system, too much and you are absorbing a greater, potentially unnecessary cost to your operation. Historically to today, mines have relied almost exclusively on operator experience to avoid both ends of the spectrum and to conservatively designed thicknesses to avoid the former. High tech approaches to laser scanning of the heading to be sprayed and the associated computerized control of the spray boom are currently in the testing phase. Non-destructive, instantaneous means of measuring applied concrete thickness either sonically or through ground penetrating radar have been discussed but are not yet readily available.

No matter how one slices it, sprayed concrete requires concrete. The ability of an operation to call up supply on short notice, regardless of the time of day, becomes increasingly important with depth, as in the case of deep level block caving mines. Hydration control agents are available today to assist this process and, for example, concrete can be batched on 2nd shift for consumption on 3rd shift (in fact, the concrete can be kept “fresh” for up to 72 hours). Technology suppliers are also working on innovative means for material transfer and underground batching plants should become more of a phenomenon going forward.

Ground support experts are also challenging concrete technology suppliers to look at cost effective means of further increasing the ductility of sprayed concrete beyond that already provided by fibre reinforcement. Polymeric addition is one example of this work.

In conclusion, while technology developments are sure to drive sprayed concrete forward, it has clearly established a dominant presence on the global mining scene and figures to be a ground support method of choice, typically in conjunction with bolt or dowel reinforcement, for years to come.