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Sprayed concrete nozzle operator training and certification

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ABSTRACT: Quality sprayed concrete (shotcrete) is the product of a complex interaction of numerous factors. One of the key factors in achieving a cost effective, high quality concrete is the knowledge, skill and experience of the nozzleman. This paper discusses the state of play in the international sprayed concrete community with regard to nozzle operator training and certification, including a number of independent training and certification programs being developed or provided by organizations in Europe and America. The paper also presents a Queensland Government accredited training package for shotcrete operators which is competency-based, and includes theory and practical training. The training program is aimed at developing a core understanding of concrete operations in an underground environment, progressing from pump operator to nozzle operator and finally to shotcrete project management.

1 INTRODUCTION

1.1 *Background*

Shotcrete has been in use for just over 100 years with the first use being dry mix followed by wet mix after the second world war. It has a long history of use in a wide range of applications where the skill and competency of the nozzleman is recognized as one of the key factors in its success (other factors being preparation of substrate, use of suitable materials, mix designs, and equipment). This was recognized even in the early years and a lot of emphasis was placed on the training of the shotcrete nozzleman as a *craftsman* (ACI, 2008).

There are no universal standards for training and certification of nozzleman as yet, however there are a number of programs either in development or implemented across the globe.

1.2 *Why train and certify nozzle operators*

Sprayed concrete use is intended to achieve a certain placed quality which is integral to the performance of the project, be it a civil load bearing structure or surface support in mining. There are numerous standards and specifications for the design of concrete structures and for preparation of the concrete itself, however it is not enough to have good standards, materials, mix design and equipment if the final placement is not carried out by a skilled operator.

A designer would never approve the building of a steel bridge with non-certified welders, yet until recently there was no such recognized independent certification for nozzlemen and even now the certification requirements are not consistent between projects.

Training and certification provided by independent institutions is a necessary requirement to ensure that concrete is placed reliably and to specification, such that quality is assured. Consistent, high quality application will give designers and project owners more confidence in using this method for cost effective development.

1.3 *Shotcrete use and certification*

Sprayed concrete is widely used in construction and mining. For example it can be found in:

- underground excavations, either for temporary or permanent support,
- soil nailing and slope stabilization,
- houses, swimming pools and various sports facilities,
- repair and reinforcement of concrete structures, for instance bridges, buildings,
- architectural and faux rock features, etc.

It is used for applications needing immediate safety and/or long-term durability. In all cases, one needs to be able to rely on the quality of the *in-situ* placement.

The method of applying sprayed concrete also depends on a number of factors such as cultural background (prevalent usage in the locality), expertise in application technique, equipment availability, logistics of supply, specific requirements of the project and costs. Generally sprayed concrete (shotcrete) is divided into two categories, being wet mix and dry mix. The shotcrete in both methods can either be applied manually or robotically.

The types of training and certification available do have common basic principles but must be distinguished as they require different expertise:

- The dry-mix process is different from the wet-mix process (the nozzle operator has to precisely regulate the water addition at the nozzle),
- Projection onto vertical surfaces is easier than projection onto overhead surfaces,
- Repairs by spraying grout in small galleries requires specific skills, and
- Robot-aided spraying requires different skills from manual spraying.

Some certification schemes distinguish between all these fields, others only some of them. Some offer several qualification levels to make a distinction between more or less skilled operators, while others do not. What is important is not to get *a* certificate but to get *the* certificate that corresponds to the requirement.

2 SHOTCRETE CERTIFICATION

2.1 *Available certification programs*

The information used in this chapter has been compiled through members of the International Tunneling Association Working Group 12 "Shotcrete Use"; and may not be complete. There are a few different types of certification organizations ranging from civil engineering companies and shotcrete contractors conducting in-house training and certification through to concrete associations and statuary bodies recommending or stipulating certification requirements.

2.1.1 *Certification in North America*

The American Shotcrete Association (ASA) was formed in 1998 by shotcrete users, practitioners, academics and suppliers to promote "the safe and beneficial use of the shotcrete process". One of the first priorities of the ASA was to establish a nozzleman training and certification program. The ASA program was started with the understanding that if the American Concrete Institute (ACI) developed a program then the ASA would withdraw its own and support the ACI.

In 1997 the American Concrete Institute established ACI Committee C660, Shotcrete Nozzleman Certification, with the mandate to develop, maintain and update programs for use in the certification of persons performing as shotcrete nozzle operators. The ACI Committee C660 developed a thorough certification program with strict policies, guidelines and procedures that responded to the needs of the shotcrete industry. It also vetted knowledgeable persons in the shotcrete industry to act as ACI approved examiners. This program was rolled out in 2001 and replaced the ASA program (Morgan & Dufour, 2009). This certification program is the most widely used with over 800 ACI certified shotcrete nozzle operators. It is intended to certify experienced nozzle operators (prerequisite: 500 hours of verified work experience as a nozzle operator or operator-in-training). It certifies both theoretical knowledge and practical ability. It distinguishes four categories of work:

- Wet mix process, vertical position only,
- Wet mix process, vertical & overhead positions,
- Dry mix process, vertical position only, and
- Dry mix process, vertical & overhead positions.

The examination sessions are conducted by local sponsoring groups of which there are two: the ASA, which administers examinations in English and Mexican Spanish, and Laval University, Quebec, Canada which administers examinations in French and English. The ASA requires the examination candidates to first take the ASA Shotcrete Nozzleman Training before sitting for the certification. This is to impart a consistent message regarding best shotcrete practice to all participants, and also to improve the chances of nozzle operators passing (there was a high failure rate in the written examination prior to this training initiative).

In addition to shotcrete nozzleman certification, many projects with structural shotcrete now also require pre-qualification of the entire shotcrete crew for the specified project by shooting and evaluation of a pre-construction mock-up. After shooting, the mock-ups are evaluated by coring or diamond saw cutting to expose intersecting reinforcing steel, so that the quality of the workmanship can be assessed. Cores can also be taken from locations without reinforcing steel, or separate plain shotcrete test panels, to prequalify the shotcrete mixture design supplied. Parameters evaluated can include compressive strength, boiled absorption and volume of permeable voids (ASTM C642, 2006).

2.1.2 *Certification in France*

A certification scheme has been available since 2001 in France from ASQUAPRO, a French non-profit-making technical association for the "Quality of Sprayed Concrete and Mortars" (ASQUAPRO, 2009). This scheme is based on a Canadian certification program developed for the Ministry of Transport from Quebec (MTQ) in 1995–96. The Canadians have since worked with the ACI and now use that as the standard program.

As with ACI certification, the French also require both theoretical and practical knowledge to be tested. The major differences are as follows. The ACI prerequisite of 500 hours work is not necessary. Instead there are four levels of qualification; the first is aimed at operators with less than 100 hours experience who cannot be certified as nozzle operators but, if they pass both the theoretical and practical examinations, they can get "approval to spray" under the supervision of a certified nozzle operator. The three other certification levels correspond to increasing degrees of operating experience: "certified", "confirmed", "highly qualified" operators.

Dry and wet mix processes are distinguished but not vertical and overhead projection: the nozzle operator must spray both vertical & overhead panels. Specific certifications have been established for spraying grout in small galleries, and more recently for robotic application. The certification can be taken either at the end of a training session conducted by independent institutes, or on the premises of the companies wanting to certify their nozzle operators or on the building site.

2.1.3 *Certification in Norway*

The Norwegians have a "Concrete Educational Council" which is an industry-based association affiliated to the Norwegian Concrete Association. The Council offers both training (course content and competent trainers) and certification (examination, certificates and registration).

The competency requirements for key personnel are specified in the Norwegian Standards. The team leaders (foreman; production, control and testing) have to show that they are familiar with sprayed concrete. For underground operations the predominant application is via wet mix robotic application for which the operator is considered a crew leader and as such, must be certified.

Dry mix operators engaged in concrete repair are considered members of the concrete repair crew and do not need certification, however their team leaders do. There are three types of certification covering both manual and robotic spraying, for:

- Foremen and crew leaders
- Normal class production leaders and control & testing leaders
- Extended class production leaders and control & testing leaders.

There is no distinction between vertical and overhead position. There is no practical examination but practical experience is the first prerequisite for certification, comprising: one year for foremen, crew leaders and normal class production or control & testing leaders; or three years for extended class production and control & testing leaders. The second prerequisite is education, comprising: engineering education for production leaders and leaders of control & testing, professional education for foremen and crew leaders. The last requirement to pass the Norwegian certification is a 5-day course (or 2×2.5 days) at the end of which all participants take the same exam.

2.1.4 *Certification in Germany*

In Germany, a certificate is specifically required for the repair/strengthening of reinforced concrete structures by specific sprayed concretes or mortars containing resin. This certificate is issued after a training session by academies authorized by the "German Concrete and Civil Engineering Association". It consists of two parts, theoretical and practical (spraying concrete on a vertical surface with a high content of reinforcement). Spraying is carried out by the manual process only. It can be done either by wet or dry process. There is one single certification level, dedicated to experienced nozzle operators.

The German Standard on shotcrete, DIN 18551 (2005), requires the nozzleman to have sufficient experience and knowledge for all applications but does not mention a specific certificate.

2.2 *Certification programs under development*

2.2.1 *Brazil*

Brazil has had a certification program since 1996 (Vieira et al, 1999) and some certifications have been issued but no specific institution is responsible and the number of certifications is unknown. The Brazilian Concrete Association (IBRACON) is working to achieve nozzle operator certification as part of the Brazilian federal program of workmanship qualifications.

The certification will first focus on the dry mix process but the program could be extended to wet-mix in the future. There will be a distinction between manual and robotic projection but vertical and overhead spraying will probably not be differentiated. Examinations will cover both the theoretical and practical aspects. There will be only one certification level.

2.2.2 *EFNARC*

The European Federation of Specialist Construction Chemicals and Concrete Systems (EFNARC) was founded in 1989 and has a wide ranging membership including manufacturers, consultants, academics and contractors. An EFNARC working group is preparing a nozzle operator certification scheme. They plan to deliver a document of about 200 slides for self-study, in 2009. The certification will cover the field of robotic projection of wet concrete for rock support, including vertical and overhead projection, as well as spraying into lattice girders and tunnel profiles.

The EFNARC certification scheme begins with examiners' certification during sessions organized by VSH in the test gallery at Hagerbach. The duration of the examiners' course will be 2 or 3 days. The second step will be the local certification of nozzle operators (on site) validated by approved examiners after providing a nozzle operator course in the local language. The theoretical exam will be a 50-question multiple choice paper. The practical exam will consist of spraying concrete with a robot and testing its consistency. There will also be oral and visual examinations.

2.2.3 *Sweden*

The Swedish Shotcrete Center and Vattenfall Utveckling, consultants and Research & Development organisations, commenced certification of nozzle operators in Sweden in 2006. The certification examination was theoretical and written. Since then, a new working group has developed a programme for certification of supervisors and nozzle operators. The working group is drawn from mine workers, contractors, the Swedish National Road Department, the Swedish National Rail Department, suppliers, Vattenfall Research and Development, and others.

Examinations will be theoretical and practical, and they will be taken after a 40 hour training course, called "rock support and repairing with shotcrete". The education before certification will be the same for supervisors and nozzle operators and therefore there will be only one certification level but different requirements for prior knowledge. Certification will not distinguish between vertical and overhead position, manual and robotic spraying.

Table 1. Certification relative to application method (after Larive, 2009).

Entity/ Location	Process		Type of spraying	
	Dry mix	Wet mix	Manual	Robotic
ACI	✓	✓	✓	
ASQUAPRO	✓	✓	✓	✓
Norway	✓	✓	✓	✓
Germany	✓	✓	✓	
Sweden	✓	✓	✓	✓
EFNARC		✓		✓
IBRACON	✓		✓	

Table 2. Certification relative to certification level and training (after Larive, 2009).

Entity/ Location	Level of certification		Training	
	One level	Several levels	Pre-requisite	Separate
ACI	✓			✓
ASQUAPRO		✓		✓
Norway		✓	✓	
Germany	✓		✓	
Sweden	✓		✓	
EFNARC	✓		✓	
IBRACON	✓			✓

2.3 *Summary of certification programs*

The types of certification and relationship to application and training are summarized by Larive (2009) and are reproduced below (Tables 1 & 2). Larive & Gremillion (2007) provide more information on the contents of examinations; pass requirements, panel assessments, practical tests, duration of validity and re-examination conditions.

3 TRAINING

As discussed above, training is provided in North America by ASA as a prerequisite for the ACI certification. In Europe independent institutions such as CPO (training organization near Epernon, France) and ABCCR (training organization in Port-Marly, France) provide training in parallel with the ASQUAPRO produced publications. The Norwegian, German and Swedish certification schemes require attendance at training sessions or study of training material. The Brazilians plan to separate the two aspects of training and certification with IBRACON in charge of certification and other institutions providing training. The vast bulk of the theoretical and practical training being conducted around the world is through equipment suppliers and admixture manufacturers (Normet, Jacon, BASF, TAM, SIKA etc). This is particularly relevant for the wet mix robotic process for tunneling and mining projects where such courses are tailored for the client's requirements.

A number of shotcrete contractors in mining (Jetcrete and Macmahon in Australia) also have structured training programs for their crews. These are usually carried out on the worksite. Civil engineering companies seeking to raise standards also conduct training and certification (Hendrix, 1983). Some of this certification is in house (Morgan Est, UK) but others are through an independent body (Freyssinet in France).

3.1 *A shotcrete training and certification program in Queensland, Australia—case study*

3.1.1 *The training program*

A Queensland Government accredited training program has been developed by Stratacrete Limited for robotic application of wet mix shotcrete. This program has been developed to assist shotcrete operators working in the mining industry to meet or exceed nationally recognized standards of competence established for this skill. It has been designed in accordance with competency-based training concepts and relates directly to Certificates (II to IV) and Diploma in Metalliferous Mining Operation (DEST, 2005).

All learning material, assessment instruments, activities, and related resource documents covered in this program relate to the application of shotcrete by mine personnel. Changes to equipment, company operating or mining procedures, policy, or production techniques are reflected in the instructional material. This program has been designed as an instructional resource comprising five levels (Loncaric & Donnelly, 2009):

- Level 1—Trainee Shotcrete Operator,
- Level 2—Pump Operator,
- Level 3—Nozzle Operator,
- Level 4—Advanced Nozzle Operator (or Trainer-Assessor),
- Level 5—Project Manager.

The requirements for the training are implemented in accordance with Australian Quality Training Framework standards for RTOs (Registered Training Organizations). Any substantial alteration to the assessments, resource material, or management of the program without the approval of the RTO will void the quality assurance.

The training program involves both theoretical (classroom based) and practical (on the job) training with written reference information provided. The following list of topics is covered in the training. The topics have been grouped to provide a staged progression from novice to expert operator. The first two levels (Tables 3 & 4), when successfully completed, will meet the knowledge requirements of the MNM20205 Certificate II in Metalliferous Mining Operations (Underground). The third level (Table 5), when successfully completed, will meet the knowledge requirements of the MNM30205 Certificate III in Metalliferous Mining Operations (Underground).

The fourth level (Table 6), when successfully completed, will meet the knowledge requirements of the MNM40205 Certificate IV in Metalliferous Mining Operations (Underground).

The fifth level (Table 7), when successfully completed, will meet the knowledge requirements of MNM50105 Diploma of Metalliferous Mining (Open Cut and Underground).

3.1.2 *Assessment*

The learning outcomes are confirmed through the assessment instruments provided with this training program. Trainees will be deemed to have acquired the desired competency standard when they can demonstrate to an accredited assessor that they can safely and efficiently apply shotcrete in accordance with the Performance Criteria identified in the appropriate Competency Standards.

RCC (Recognition of Current Competencies) and RPL (Recognition of Prior Learning), are ways of recognizing that a person has acquired the necessary competencies through previous learning or

Table 3. Level 1—Trainee shotcrete operator.

Description	Estimated time
Overview of training program	2 hours
QMITAB generic metalliferrous core induction program	10 hours
QMITAB generic metalliferrous elective induction program	5 hours
Introduction to shotcrete and illustrated glossary	2 hours
Underground communication	2 hours
Plan and organise individual work	2 hours
Hazard identification and risk assessment	3 hours
Site induction	30 hours
Site light vehicle ticket (equipment manual)	10 hours
Concrete basics, including fibre	3 hours
Batch plant operator (theory and quality control)	3 hours
Site agitator ticket (equipment manual, formal training component)	30 hours
Shotcrete Rig (equipment manual, formal training component)	40 hours
Maintenance and minor repairs	10 hours
Consolidation of skills and allowance for scheduling	30 hours

Table 4. Level 2—Pump operator.

Description	Estimated time
Job safety analysis	3 hours
Crew communication	3 hours
Introduction to ground preparation	10 hours
Maintenance trouble shooting	10 hours
Electrical and hydraulic trouble shooting	10 hours
Mix trouble shooting	10 hours
Factors affecting mix performance	5 hours
Fibre balls	2 hours
Extra water	2 hours
Oversize aggregate	2 hours
Admixtures and dosages	5 hours
Quality implications	5 hours
Rejection of loads	5 hours

Table 5. Level 3—Nozzle operator.

Description	Estimated time
Supplier communication	5 hours
Site specific ground awareness course	10 hours
Australian Standards in testing	10 hours
Certification to spray test panels	30 hours
Log of fifty test panels to required standard	40 hours
Understanding of tensile strength	5 hours
Flexural strength	5 hours
Shear strength	5 hours
Bond strength	5 hours
Develop standard operating procedures	5 hours
Senior first aid certificate	15 hours
Advanced admixtures and dosages	5 hours
Practical application of stabilizers	5 hours
Practical application of accelerator	5 hours
Practical application of water reducer	5 hours
Calculations of dosage rates by weight of cementitious material	10 hours
Justifying rejection of loads	5 hours
Limits of admixture quantities	5 hours
Consolidation of skills	40 hours

Table 6. Level 4—Advanced nozzle operator.

Description	Estimated time
Supervisory communication	10 hours
Leadership and motivation	10 hours
Introduction to contract management	10 hours
Supervisor for up to 24 hour, 7 day operation	40 hours
Parts of Certificate IV Workplace Training and Assessment	30 hours
Consistent procedures (quality control)	15 hours
Implement and maintain standards on site	10 hours
Consolidation of skills	10 hours

Table 7. Level 5—Project manager.

Description	Estimated time
Client communication	10 hours
Advanced contract administration	10 hours
Advanced site administration procedures	10 hours
Consistent procedures across all sites	10 hours
Supervisory level in charge of a 24/7 operation with 4 crews	10 hours
Hiring procedures	10 hours
Retrenchment procedures	10 hours

experience. Regardless of how the particular skill was acquired, there is provision in the training structure to recognize this skill and provide the appropriate qualification. By providing a Statement of Attainment for competencies completed, the employee gains a skill that is recognized in any metalliferous underground operation in Australia. As each competency is completed, the employee is one step closer to a qualification recognized under the Australian Qualification Framework (AQF) (DEST, 2007).

3.1.3 *Case study on improvements due to training*

3.1.3.1 North Parkes Mine

North Parkes Mine is a block caving operation that was undergoing infrastructure development where shotcrete was part of the long term ground support. There were a few issues regarding excessive re-work and poor practice, mostly due to loss of experienced staff and training limitations. Fortunately the site had good monitoring systems in place which could be used to measure shotcrete quality before and after training. After three months of training on a single shift basis the results shown in Figures 1 to 3 were achieved.

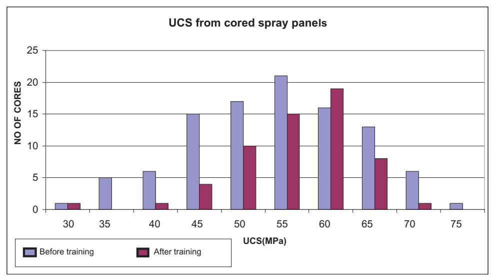

Figure 1. Improved UCS results after short term training.

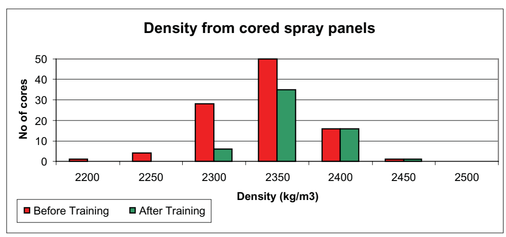

Figure 2. Improved density results after short term training.

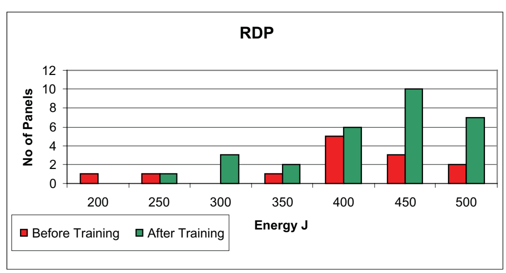

Figure 3. ASTM C1550 round panel energy absorption at 40 mm.

Note the mean strength increased from 55 MPa to 60 MPa and the distribution of results went from a Normal curve to a curve more skewed towards higher strength. Accelerator usage was specified at less then 21.5 L/m^3. Before training, accelerator was applied within specifications 65% of the time. After training it was applied within specifications 85% of the time. The in-situ density improved after training with the mean increasing slightly from 2340 kg/m^3 to 2360 kg/m^3 and the distribution showing less scatter (Figure 2). The ASTM C1550 round panel tests also showed improvement with the mean energy absorption rising from 400 Joules to 450 Joules (Figure 3).

One of the significant improvements the trainers noticed was the development of an ability by the shotcrete operators to plan how they would spray a heading or a particular area that required rehabilitation. This resulted in significant improvements in uniform thickness and reduced fall out. Unfortunately rebound including fallout was not measured or calculated for this short term training program. The use of depth stamps also improved quality assurance on thickness (Figure 4).

3.1.3.2 Peak Gold Mine

In this example the mine owner-operators were re-starting their shotcrete system after resolving supply issues. The mine decided to set up a temporary batch plant and to return employees from other duties to shotcrete operations. The mine had also recently purchased and commissioned a new Maxijet shotcrete rig.

After implementing a short term training program on site the following results were achieved:

- Increase in average UCS from 32.5 to 35 MPa (7.6% rise),
- A saving in excess of 40 litres per heading in accelerator usage,
- There was a measurable improvement in the quality of the shotcrete applied underground,

Figure 4. Thickness Stamps (note "X" shaped stamps).

- There was a measurable improvement in the performance of the shotcrete operators,
- Improved operator understanding of the use and control of the Maxijet including concrete pump speed and pressure, accelerator pump setting and engine speed setting.

3.2 *Recommendations for implementing a training program*

Before a training program can be devised, an initial audit of the shotcrete system on site should be conducted involving all parties (including suppliers) who contribute to the shotcrete system. Ideally this would require 6 to 8 weeks to allow for the collection of suitable data. This data will ideally consist of:

- UCS test cylinders at the batch plant,
- Test panels sprayed underground for density and operator UCS tests,
- Panels sprayed underground to determine energy absorption via the ASTM C 1550 round panel test or the European square panel test EN 14488-5,
- Thickness stamping or drilling to determine applied thickness and consistency,
- Accelerator usage measured at the pump and reconciled to what the mine can measure,
- Rebound measured for each operator or calculated by comparing shotcrete volumes batched to shotcrete volumes placed.

Collecting data can result in improvements in the shotcrete system simply because personnel are now being introduced to existing or new procedures for placing shotcrete, that were not previously well known or established on site.

The site can then choose to either implement its own training program or to bring in external consultants and expertise. Before training can be implemented a knowledge-base must be established and skills-base accessed. The quality of the knowledge and skills captured will determine the success of the training program. To implement the program, time and resources will have to be allocated to ensure personnel are afforded a fair opportunity to develop their shotcrete skills and knowledge. The shotcrete and training system must be monitored to ensure there is: no loss of core skills or knowledge as personnel are promoted or move away; no obsolescence in procedures as equipment, materials, chemicals and legislation are developed; and inadequate ground support or unmet legal requirements. Once a stable training program and shotcrete system are in place it becomes much easier to establish the benefits of optimizing the mix design, faster setting accelerators, curing sprayed shotcrete, changing equipment, use of different fibers, and controlling thickness.

4 CONCLUSIONS

There is a significant gap between the critical impact that the nozzle operator has the on quality of sprayed concrete and the independent training and certification that is available. This is recognized as a concern by sprayed concrete associations and there is currently a strong demand and effort to implement training and accreditation. The leaders in this area are presently the ACI and ASA in North America who have widely recognized certification programs for nozzle operators. The Europeans are taking a similar approach though ASQUAPRO who distinguish their certification on four levels ranging from "operator-in-training" to "highly-qualified" nozzle operator. Norway and Sweden place emphasis on certifying all staff involved in shotcrete, not just the nozzleman. Germany emphasizes skills for repair/reinforcement of reinforced concrete structures.

The Brazilian and the EFNARC certification schemes will, at least in the beginning, be dedicated to specific fields of application: the dry-mix process for the first scheme and the wet-mix process with robotic spraying for the last.

In Australia, a few shotcrete contractors conduct structured training programs in-house. One contractor, Stratacrete, has achieved state government accreditation and is providing independent training to mining companies and contractors. This training has had a significant impact on shotcrete performance and costs.

If the sprayed concrete industry can demonstrate, consistent and quality placement of shotcrete by certified nozzleman, designers and project owners will have increased confidence in using this method of placement. This will benefit the spraying industry and will also lead to efficiencies in the use of sprayed concrete. Therefore it is imperative that shotcrete certification be based on quality training and transparent assessment which is monitored by independent organizations.

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