# The Influence of the Nozzle Tip on Shotcrete Spray Performance

*By Pierre Siccardi, Achraf Laradh, Simon Bérubé, and Marc Jolin*

Shotcrete placement is by definition driven by the particles' high velocities. The kinetic energy provided by the velocity is how we obtain the desired consolidation of the in-place material upon impact to achieve good performances. Thus, it is important to look at the velocities found in the shotcrete spray using a rigorous approach to compare different nozzles.

## WHAT WE KNOW

In the past, some researchers have tried to explore the rebound phase of shotcrete placement. The most advanced work, made by Armelin (1997), led to a model of a single particle impact on an elasto-plastic substrate. His work especially outlines the importance of the velocity on the particle impact energy, and more widely, on overall rebound.

To have a better understanding of what is going on during the spraying, the placement and rebound phases, this theory had to be extended from a single particle to the entire spray stream. Past research at the Université Laval Shotcrete Laboratory discovered specific patterns in the shotcrete spray for each process and equipment employed. Nicolas Ginouse was the first to develop a method to properly measure particle velocities from the nozzle tip to the receiving surface. By filming the spray with a high-speed camera and tracking the particles frame by frame, he was able to evaluate the particles' velocities in the entire spray stream. Noteworthy, he found that particles kept accelerating after exiting the nozzle as the maximal velocities measured are greater at 1.0 m (3.2 ft) than at 0.5 m (1.6 ft) from the nozzle tip (Fig. 1).

Also, velocities are not uniformly distributed around the central axis of the spray stream. The wet-mix process produces more uniform velocities than the dry-mix process. This means that a higher proportion of particles are travelling at a faster speed in wet-mix (Ginouse & Jolin, 2014).

Finally, one can observe that in dry-mix the exact velocity pattern changes with the type of nozzle tip. The speed reduction at the edges is more important with the double-bubble nozzle-type (in green) than the spirolet nozzle (in red).

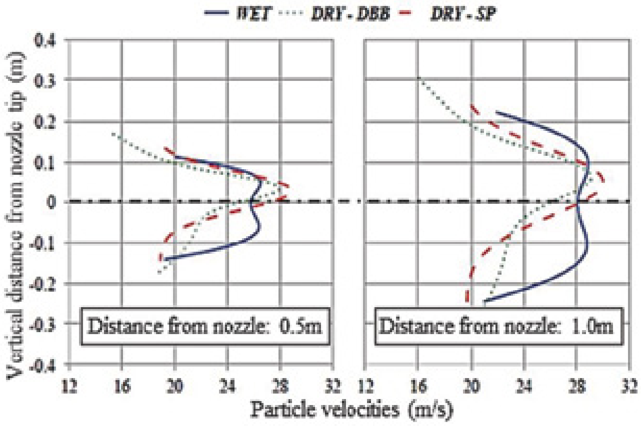

*Fig. 1: Fitted velocity profiles at 0.5m and 1.0 m for the wet-mix (in blue) and dry-mix (in green and red)*

These discoveries have provided a major step forward in our understanding of the shotcrete placement process. According to Armelin (1997), rebound is linked with the ratio between the kinetic energy of a particle and the debonding energy. Given that kinetic energy depends on the square of the speed, it is logical to believe that velocity spray patterns play a key role in rebound. Thus, the hypothesis that the lower value of rebound produced with wet-mix compared to dry-mix is partly due to their very different velocity profile within the spray stream. Thus, efficiency of the nozzle can be evaluated through analysis of the velocity patterns.

One key observation of Ginouse's study is that a shotcrete spray can be simply characterized by two parameters: the maximum velocity and the spray opening angle.

## RESEARCH DYNAMIC

The results of Ginouse's research have opened many R&D topics. Thus, a series of projects have emerged to extend the research effort on the study of the shotcrete spray. One of these research topics was about the influence of the equipment (nozzle) on the performance, especially concerning rebound, in each process.

Simon Bérubé has been a part of this momentum established at Université Laval Shotcrete Laboratory. His research (Bérubé, 2017) has focused on the influence of the nozzle on the particle velocities in wet-mix shotcrete, and on the mass distribution in the dry-mix spray stream of concrete.

This article develops one specific aspect of Bérubé's project. By using the same setup as Ginouse, this research evaluated the influence of the nozzle body and the nozzle tip shape on the spray pattern in wet-mix shotcrete.

## METHODOLOGY

This study took place in a controlled laboratory environment with conventional industrial shotcrete equipment. A shotcrete hydraulic cylinder pump, an Allentown Powercreter 10, was used to pump a modern shotcrete mixture designed for wet-mix placement. To lubricate the 50 mm (2 in.) 20 m (65 ft) long delivery hose, a cement grout with the same water/binder ratio as the concrete, was pumped before the spraying.

Fig. 2 shows the experimental set-up for the imaging device used in our facility. The 1250 frames per second capacity camera is positioned perpendicular to the screen and the shotcrete spray. The white screen helps to ensure a adequate contrast to discern particles in the spray when the processing on captured images is done. When shotcreting, the nozzle is held in a static support and kept motionless to avoid the effects due to movement of the nozzle and the material stream.

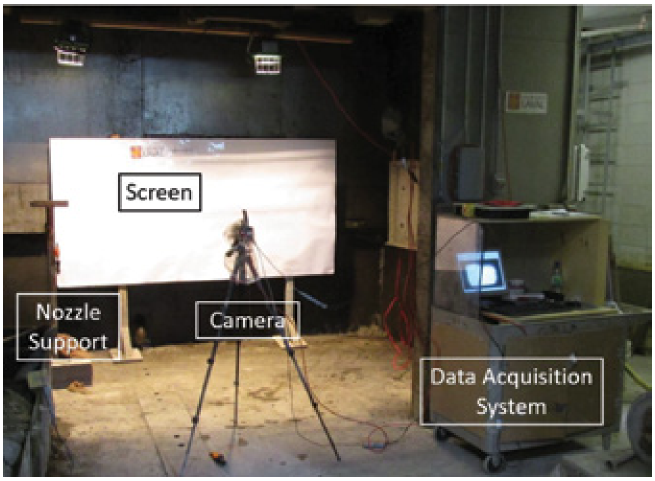

*Fig. 2: Experimental imaging device (Bérubé, 2017)*

Images are then post-processed with specialized software to track the particles image by image. With the data acquired, particle velocity profile and spray limits can be defined.

Two conventional nozzles, the so-called ACME Nozzle and the 1978 Nozzle (Fig. 3), were put to the test. Those nozzles present some interesting differences: while both air rings are similar (8 holes), the air plenum of the 1978 Nozzle is clearly thinner and narrower than the one found on the ACME Nozzle, and the ACME Nozzle has a 19.1 mm (0.75 in.) air inlet whereas the 1978 Nozzle has a 12.7 mm (0.5 in.).

*Fig. 3: Tested nozzles during experiments - ACME (top) and 1978 (bottom) (Bérubé, 2017)*

Moreover, the nozzle tips have noticeable differences (Fig. 4). The ACME Nozzle tip (referred to as long nozzle tip) is 193 mm (7.6 in.) long and has a 31 mm (1.2 in.) diameter outlet, whereas the 1978 Nozzle tip (referred to as short nozzle tip) is 130 mm (5.1 in.) long and has a 36 mm (1.4 in.) diameter outlet. The ACME Nozzle tip is therefore longer and more tapered than the 1978 Nozzle tip. Furthermore, these two nozzle tips have different rigidity due to their thicknesses and the rubber used. The long nozzle tip is stiffer.

*Fig. 4: Close-up of the nozzle tips*

## PHASE 1

The first trials of the project brought to light interesting differences in the concrete spray produced by the two nozzles presented before.

Table 1 presents the spray characteristics at 1.0 m from the nozzle outlet for the two nozzles and for two different airflows.

| Characteristics | ACME | | 1978 | |
|---|---|---|---|---|
| Airflow (ft³/min) | 150 | 200 | 150 | 200 |
| Vmax (m/s) | 24.0 | 23.5 | 16.0 | 16.9 |
| Angle (°) | 28.2 | 27.2 | 49.6 | 52.0 |

*Table 1: Spray Characteristics for the two nozzles*

As shown in Table 1, particles in the spray produced by the ACME Nozzle travels around 50% faster than the one in the 1978 spray for both airflows. Moreover, the ACME spray is half narrower than the 1978 spray.

The first interesting observation is the nozzle (body and nozzle tip) has a noticeable effect on the particle velocities and spray limits. To investigate the origin of those differences, the second step of this project was to focus more on this piece of equipment.

## PHASE 2

To explore further, the nozzle tips were switched. This way, the long nozzle tip was put on the 1978 Nozzle body, and the short nozzle tip likewise switched to the ACME Nozzle body. Table 2 presents the experimental program and the results obtained with each configuration.

| Body | Tip | Vmax (m/s) | |
|---|---|---|---|
| | | 150 ft³/min | 200 ft³/min |
| ACME | Long | 24.0 | 23.5 |
| | Short | 18.5 | 23.0 |
| 1978 | Long | 19.5 | 22.4 |
| | Short | 16.0 | 16.9 |

*Table 2: Maximum velocity for each nozzle configuration*

## DISCUSSION

From a theoretical rebound point of view, the ACME Nozzle body combined with the long nozzle tip proved to be the best configuration achievable, considering the particles velocities. For both 150 and 200 ft³/min air flow, particles traveled around 24 m/s (79 ft/s). The worst configuration would be the 1978 Nozzle body combined with the short nozzle tip. Particles travel around 16 to 17 m/s (52 to 56 ft/s) regardless of the airflow.

## INFLUENCE OF THE NOZZLE BODY

To evaluate the nozzle tip efficiency in future research, velocities will be compared using the 150 ft³/min air flow since that is the more critical case for spray velocities. Using the same nozzle body, the short nozzle tip always produced lower particle velocities compared to the long nozzle tip.

It is interesting to mention that, at 200 ft³/min, a good nozzle body (ACME) combined with the extra airflow helped to reduce the "bad" effect of the short nozzle tip.

## CONCLUSION

This brief study showed the importance of choosing both the right nozzle body and the right nozzle tip to ensure optimal placement conditions. Moreover, it seems that increasing the airflow will not always increase particle velocities. Cutting the end of the nozzle tip reduces back thrust and may facilitate nozzle movement for the nozzleman and is sometimes seen on construction sites. However, this practice will lead to a reduction in the shotcrete spray velocity and in turn reduce the shotcrete placement quality and overall performance.

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## References

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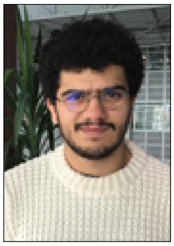
*Following a bachelor's degree in mechanical engineering from the Arts et Métiers in France,* ***Pierre Siccardi*** *pursued his studies at Université Laval, Québec, Canada where he obtained his master's degree. His research project on shotcrete nozzles led to the filing of a patent. He is currently pursuing his PhD under the supervision of Prof. Marc Jolin. His project now focuses on the homogeneity and the adjustment of concrete mixes in a mixer truck using an on-board system.*

***Simon Bérubé*** *earned his civil engineering bachelor's degree from Université Laval in 2014. Following that, he completed his master's degree in the same field in 2018 under Dr. Marc Jolin, during which he undertook a research project on shotcrete equipment modelization. Simon Bérubé now works for CIMA+ since 2016, a private engineering firm located in Quebec City.*



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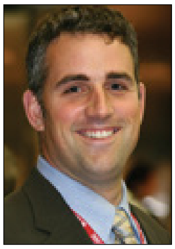

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