The Hidden Cost of Nozzle Wear: HOW A 10% INCREASE IN NOZZLE DIAMETER REDUCES AIR VELOCITY BY 17%

By Raúl Bracamontes

In shotcrete operations, nozzle condition is often underestimated. Crews typically monitor pump output, airflow, slump, and accelerator dosage — but nozzle wear rarely receives the same level of attention. From a fluid mechanics standpoint, however, nozzle wear has a direct and measurable effect on air velocity, impact energy, consolidation, and ultimately shotcrete placement quality. This article explains the phenomenon mathematically, and translates it into practical field implications.

For this article, most comments refer to a wet-mix shotcrete nozzle tip with a manufactured internal diameter of 38 mm (1.5 in.).

Figs. 1 and 2: Manometer (ABOVE) for pressure measure and flowmeter (BELOW) for airflow measurement

THE PHYSICS BEHIND NOZZLE WEAR

To understand how the shotcrete nozzle works requires basic fluid mechanics. Bernoulli's principle is fundamental to understanding how the nozzle works in the shotcrete process.

Bernoulli's principle explains the relationship between pressure, velocity, and potential energy. It states that when the velocity of a fluid increases, its pressure decreases, and vice versa, assuming the total energy in the flow remains constant.

> **IN THE KNOW: The compressor supplies both air pressure and air volume, and the air must be free of oil and water. Air pressure is measured using a manometer, and airflow can be verified using a flowmeter.**

In a shotcrete nozzle, compressed air pushes the concrete mixture. As the air passes through a reduced cross-section inside the nozzle, several things occur:

1. The flow area decreases
2. Air pressure decreases
3. Air velocity increases

This increase in velocity allows the concrete to exit the nozzle with high kinetic energy, which is essential for proper compaction against the receiving surface. Several phenomena occur simultaneously inside the nozzle:

1. **Flow Acceleration:** Compressed air accelerates as it passes through the reduced cross-section.

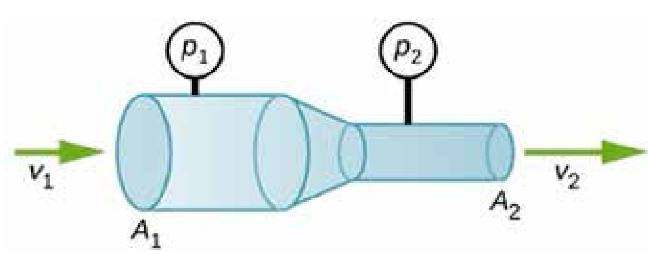
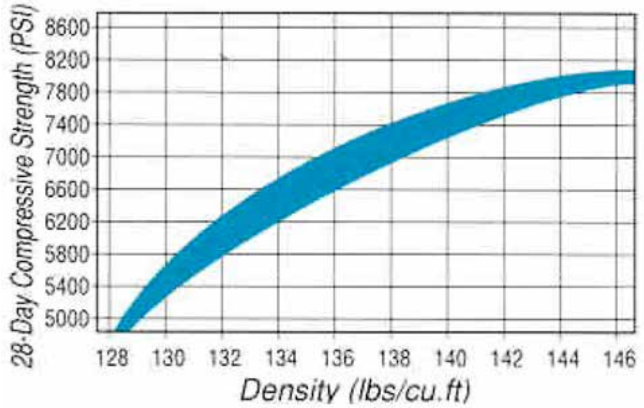
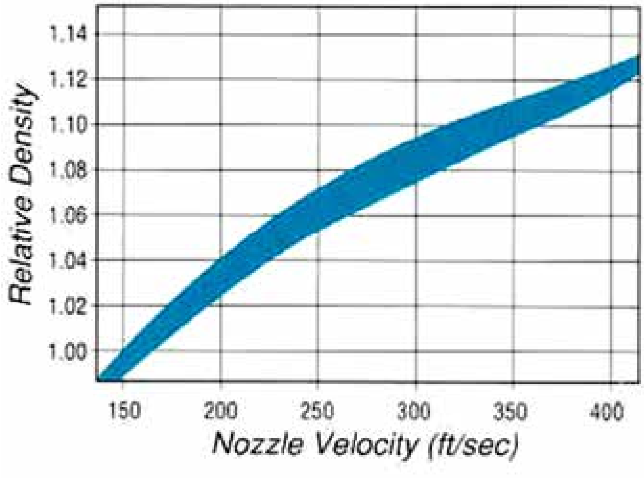


Fig. 3: Bernoulli Nozzle

Fig. 4: Shooting wet-mix shotcrete





2. **Particle Entrainment:** Cement, sand, and aggregate particles are carried and accelerated by the air stream.
3. **Mixing with Water (Dry-Mix Process):** In dry-mix shotcrete, water is introduced at the nozzle and mixed turbulently with the dry concrete material.
4. **High-Speed Projection:** The material impacts the receiving surface at approximately 20 to 35 m/s (65 to 115 ft/s) depending on the equipment and setup.

This velocity produces compaction and adhesion to the substrate. In other words, this provides the structural bond which is the hallmark of quality shotcrete placement.

For wet-mix shotcrete, the air introduced at the nozzle must be sufficient to separate and accelerate each of the concrete particles, allowing proper consolidation when they impact the receiving surface.

According to ACI 506, for wet-mix hand-spray shotcrete using a 2 in. (50 mm) hose, compressors should typically provide:

- Volume 200 to 375 CFM (5.6 to 10.6 m^3/min)
- Pressure 100 to 125 psi (6.9 to 8.3 bar)

This airflow helps generate exit velocities of approximately 27 to 36 m/s (60 to 80 mph), which are necessary for proper shotcrete placement. This level of force, however, will eventually wear out the material at the nozzle. This both increases the internal diameter of the nozzle and weakens the nozzle membrane from containing the force of material outflow.

AIRFLOW AND THE CONTINUITY EQUATION

Airflow through a shotcrete nozzle follows the continuity equation:

$Q = A\ V$

Where:

Q = Volumetric flow rate (m^3/s or ft^3/s)

A = Cross-sectional area (m^2 or in^2)

V = Air velocity (m/s or ft/s)

For a given compressor, the volumetric flow rate (Q) is essentially constant. Therefore,

$$V = \frac{Q}{A}$$

If the nozzle diameter increases due to wear, the cross-sectional area (A) increases. In other words, when airflow (Q) remains constant, the velocity (V) must decrease, affecting your exit velocity and thus compaction and substrate adhesion.

MATHEMATICAL EXAMPLE: 10% NOZZLE WEAR

For this example, we assume the nozzle tip is rigid enough that air pressure does not further deform it. In practice, thinner nozzles may expand slightly under pressure, which can further increase the diameter.

ORIGINAL NOZZLE DIAMETER

38 mm (0.038 m) (1.5 in.)

$$A_1 = \frac{\pi(0.038)^2}{4} = 0.00113\, m^2$$

$$A_1 = 0.00113\, m^2$$

Equivalent area: 1.77 in²

WORN NOZZLE DIAMETER (10% INCREASE)

41.8 mm (0.0418 m) (1.65 in.)

$$A_2 = \frac{\pi(0.0418)^2}{4} = 0.00137\, m^2$$

$$A_2 = 0.00137\, m^2$$

Equivalent area: 2.14 in²

AIRFLOW CONVERSION

Given airflow: 10.6 m³/min (375 CFM)
Converted to seconds:

$$Q = \frac{10.6}{60} = 0.1767\, m^3/s$$

$$Q = 0.1767\, m^3/s$$

Equivalent: 6.22 ft³/s

AIR VELOCITY CALCULATION

WITH A NEW NOZZLE

$$V_1 = \frac{0.1767}{0.00113}$$

$$V_1 = 155.8\, m/s$$

Equivalent: 511 ft/s

WITH A 10% WORN NOZZLE

$$V_2 = \frac{0.1767}{0.00137}$$

$$V_2 = 128.7\, m/s$$

Equivalent: 422 ft/s

VELOCITY LOSS

$$\text{Velocity Loss (\%)} = \left(1 - \frac{V_2}{V_1}\right) \times 100$$

$$= \left(1 - \frac{128.7}{155.8}\right) \times 100 \approx \mathbf{17.4\%}$$

Result: ≈ 17.4% reduction in air velocity

WHAT DOES A 17% VELOCITY REDUCTION MEAN?

In shotcrete placement, impact energy (E) is directly related to velocity. Note that m in the equation is the mass of the concrete.

$$E = \frac{1}{2} m V^2$$

Because kinetic energy depends on the square of velocity, even a moderate reduction in velocity (17.4%) results in a much larger reduction in impact energy. This affects:

- Consolidation
- Bond to substrate
- Encapsulation of reinforcement
- Rebound
- Surface density
- Long-term durability

Even if pump output and compressor settings remain unchanged, shotcrete quality may decrease simply because the nozzle is worn, if the shotcreter remains at the same distance.

FIELD COMPENSATION: MOVING THE NOZZLE CLOSER

Impact force also depends on distance from nozzle to substrate. As the material travels through the air, velocity decreases due to drag and turbulence. If nozzle wear reduces exit velocity, the only way to partially compensate (without increasing airflow) is to reduce the shooting distance.

For a 10% diameter increase:

Original distance
1.0 m (3.3 ft)

Required adjustment
0.26 m (0.85 ft) closer

New distance: 0.74 m (2.4 ft)

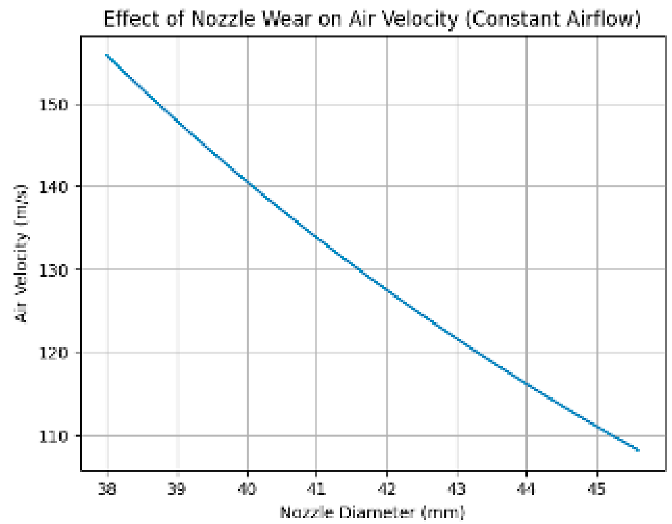
This helps recover some of the lost impact energy. Some shotcreters may rely on this to compensate for the decrease in velocity. Rather, the need for this compensation should be taken as an indicator that the nozzle has exceeded its useful life and should be replaced.

THE COMPRESSOR MYTH

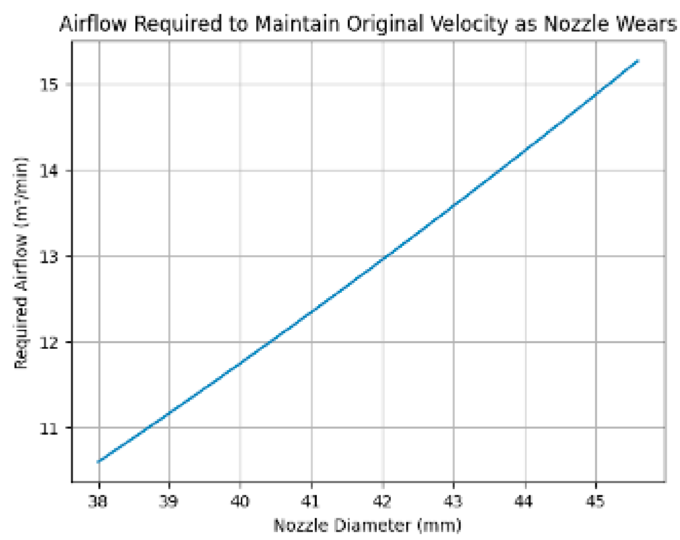
A common field reaction is: "Let's add more air." Mathematically, to maintain the same exit velocity:

$$Q_{new} = A_{worn} \cdot V_{original}$$

This requires higher compressor airflow (CFM).



Effect of nozzle velocity wear on air velocity (constant air flow) keeping the nozzle at the same distance



Example:

Nozzle Wear	Required Airflow
0%	10.6 m^3/min (375 CFM)
10%	≈ 12.8 m^3/min (452 CFM)
20%	≈ 15.3 m^3/min (540 CFM)

Because area increases with the square of the diameter, airflow demand increases rapidly. However:

- Compressors may not have reserve capacity
- System efficiency decreases

The correct solution is not to continually increase airflow. The correct solution is to replace the nozzle.

WHEN SHOULD A NOZZLE BE REPLACED?

Although project conditions vary, here is a practical rule: A 10% increase in internal diameter results in approximately a 17% reduction in air velocity and a significant loss in impact energy. In practice, losses may be even greater if the nozzle deforms under air pressure. At this point, nozzle replacement is strongly recommended.

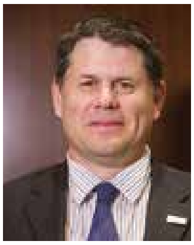
Nozzle wear is not cosmetic. It represents a measurable reduction in consolidation energy.

Conclusion

Nozzle wear is a hidden quality variable in shotcrete placement. A seemingly small 10% increase in nozzle diameter produces:

- 17% reduction in air velocity
- Significant loss of impact energy
- Reduced consolidation and adhesion

In shotcrete placement: Energy equals quality. Maintaining proper nozzle geometry is not optional — it is a fundamental quality control requirement.



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