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Paper

THE COMBINATION OF PRESSURE AND FLOW RATE IN THE EXPRESSION OF RELATIVE WATERJET IMPACT

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ABSTRACT

The expression of the effective cleaning results of high pressure waterblast cleaning is commonly given or specified in terms of operating pressure, and often may include the desired flow rate specification as well, generally determined by experience for a given application. It is also possible to estimate the effectiveness of jet impact with standoff distance; however, the existing expression utilizes only the pressure and standoff distance relative to orifice size to determine and compare values of relative performance without taking into account the flow rate or total power. The purpose of this research was to determine if it is reasonable and possible to include the effect of flow rate in combination with pressure when estimating the relative performance of jet impact with standoff distance, and how this might vary in materials with various and differing responses to jet impact.

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1. INTRODUCTION

When recommending or specifying a waterblast cleaning system for cleaning of vessels and pipes, the first step is evaluating the application of high pressure water in terms of pressure, flow and tooling requirements to be within effective jet impact range while also attempting to best combine performance with simplicity. An example would be comparing the potential use of a simple 2D or 3D tool in a vessel, supported by a hose from above with the jet nozzles being up to several meters away from the interior surfaces, to the complexity of scaffolding inside the vessel and erecting a framework to support the jet nozzles within centimeters of the surfaces to be cleaned. This evaluation would compare potential combinations of pressure and flow, applied to account for standoff distances of the jets and pressure losses in the system delivering the high pressure water, to estimate the expected jet impact at the surface to be cleaned.

The existing jet impact calculation, Equation 1, utilizes the pressure at the nozzle, the orifice size of the jet, and the standoff distance from the surface to estimate the expected jet impact, given in terms of pressure, since every waterblast job is discussed in terms of what pressure is required to be effective. This calculation came from the curve of jet performance with standoff distance, Figure 1, by fitting a curve equation to the empirical data. The curve for jet performance does incorporate flow in terms of the ratio of standoff distance to nozzle diameters, as nozzle diameter and pressure determine flow rate. This method of estimation multiplies the percentage of jet performance at a given standoff distance ratio by the pressure at the nozzle. However, when comparing two possible combinations of pressure and flow where the flow rate and power at pump is greatly differing but the calculated jet impact is similar, as shown in Figure 2, it raises the question of how the impact calculation should also incorporate the potential effect of the flow or total power of the jet. The purpose of this testing was to determine how an additional factor for flow might be included in a jet impact calculation.

$$\text{Impact at Surface} = .81022 \text{ x } e^{(-.00177072 \text{ x Standoff Distance / Orifice Diameter})} \text{ x Pressure at Nozzle}$$

Equation 1.

Where Impact at Surface and Pressure at nozzle are in same units (psi or MPa), and Standoff Distance and Orifice Diameter are in same units (inches or mm).

2. TEST ARRANGEMENT

Testing was performed in two sample types of concrete, mixed to have strengths of 2500 psi (17 MPa) and 5000 psi (34 MPa); both having 20 mm aggregate size and allowed to cure for 30 days. An air motor and gearbox was used to drive a rotating jet head at 400 rpm, holding either one or two nozzles, which was traversed across the concrete samples at a rate of 2 meters per minute; the test equipment is shown in Figure 3. A steel plate mask was used to control the area of jet contact. Standoff distances of 25 mm and 300 mm were used, at pressures of 10,000 psi (69 MPa) and 20,000 psi (138 MPa), with flow rates from 7 to 46 gpm (26 to 190 lpm). Measurement for volume removed was completed on each test section by filling with glass beads; Figure 4 illustrates a typical concrete block after testing.

3. TEST RESULTS AND ANALYSIS

3.1 Efficiency of Pressure and Material Properties

Every material that can be cut or removed by high pressure waterjet has a minimum, or threshold pressure, at which the first effects are seen. As pressure is increased above this threshold pressure, the efficiency of material removal increases, until at an optimum pressure value commonly stated to be between 3 and 5 times the threshold pressure. The information about material response to high pressure waterjet is obtained by direct testing, estimated by field experience, or by comparison to known materials having similar properties. In this case, the two strengths of concrete show different optimum pressures, along with the weaker concrete requiring less power to remove, as illustrated in Figure 5. This result is typical for like materials having different strengths, but does not apply where other material properties may dominate in response to waterjets. An example is the comparison of the reasonable effectiveness of a 15,000 psi (100 MPa) waterjet on granite, having a compressive strength of 28,000 psi (190 MPa), to the lack of waterjet effectiveness on limestone, with a strength of 7,000 psi (48 MPa), due to the macro-crystalline structure of the granite and none in the limestone.

The relationship between pressure and efficiency of material removal proved to have the greatest effect on the response to varying the flow; without some knowledge or application of this relationship it would not be possible to accurately incorporate and compare the effect of flow rate.

3.2 Effect of Flow

Figures 6 and 7 plot the effect of increasing flow on material removal in both types of concrete, at two pressures and two standoff distances. The results show the effect of increasing flow is strongly dependent on the pressure and material properties relationship. The 25 mm standoff distance and the 20,000 psi (138 MPa) pump pressure is well into the optimum pressure range for both materials, and increasing the flow results in a 1:1 ratio of performance gained to flow rate increase. The data for the 10,000 psi (69 MPa) pump pressure in the 17 MPa concrete at the 25 mm standoff distance shows an average ratio of 3:4 in performance gained to flow rate increase, while the same applied to the 34 MPa concrete results in a lower ratio of 1:2.

The 300 mm standoff distance results in deterioration of jet impact, where the impact calculation predicts the 20,000 psi (138 MPa) jet would be decreased to an equivalent impact range of 9900 to 12,500 psi (68 to 86 MPa). When compared to the results of the 10,000 psi (69 MPa) tests, the two curves have nearly the same ratios and performance, as would be expected from the prediction.

3.3 Effect of Dividing Flow into Two Nozzles

Each test combination of pressure and flow was performed with a single jet and with two jets. Figure 8 shows the average result of the comparison between the single jet performance and two jet performance. The single jet performance was on the average less than 10% better, showing an increasing benefit with increasing power. Rotation speed and feed rate were kept the same between the two test types, effectively resulting in twice as many jet impacts by the smaller double jet configuration. This result of only a slight loss of effectiveness with two jets is most beneficial as applied to tooling design, where two jets may be balanced against each other in jet reaction force, making the supporting of the tooling simpler and lighter weight.

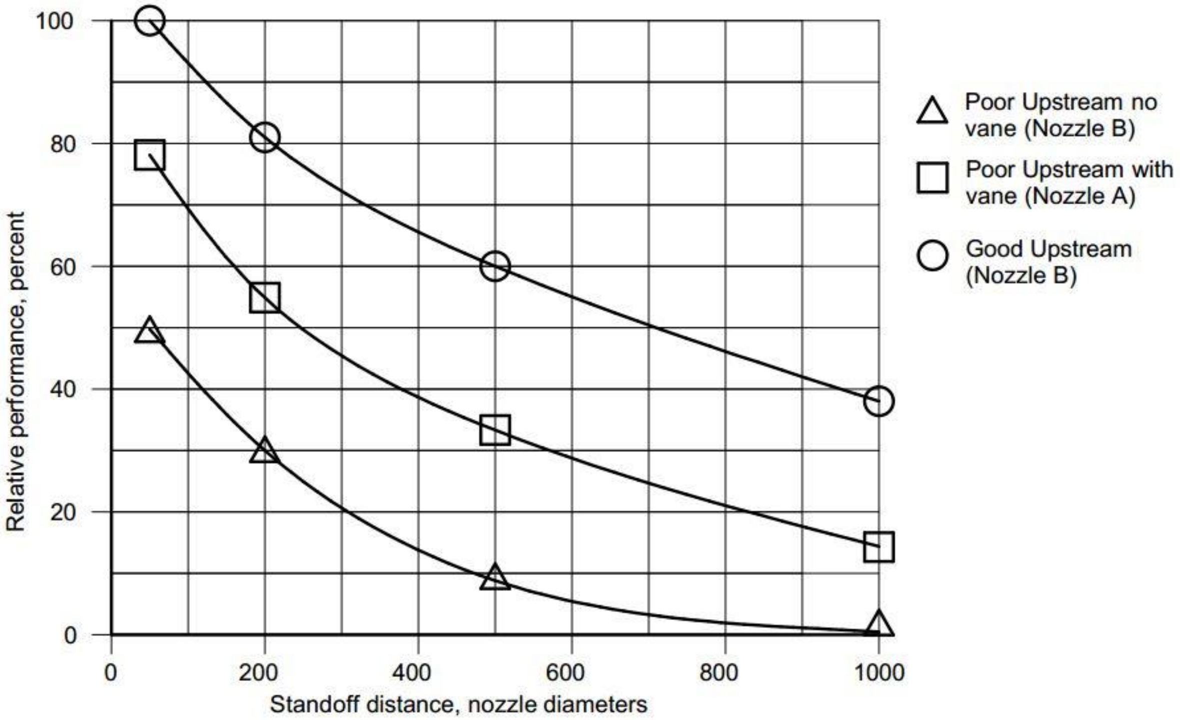
3.4 Predicted Jet Impact and Considerations for Flow

To include the flow rate in the jet impact comparisons, one might express the impact in power, which is directly proportional to pressure and flow. Figures 9 and 10 use the pressure at pump multiplied by the flow rate to plot effectiveness in material removal as a function of this power. We could also express the impact at the surface as a power, by using the calculation that estimates pressure at the surface after loss due to the standoff distance. When the power is calculated using this estimated pressure at surface and the flow rate, the resulting curves are shifted to align with the performance curves at the 25 mm standoff distance, as shown in Figures 11 and 12. However, as the power is increased by increasing the flow rate, the curves continue to fall off. If the flow rate is adjusted by the ratio of the curves' slopes of performance against flow (Figures 6 and 7), the resulting curves of Figures 13 and 14 result, now closer to alignment with the 25 mm performance curves through these compensations.

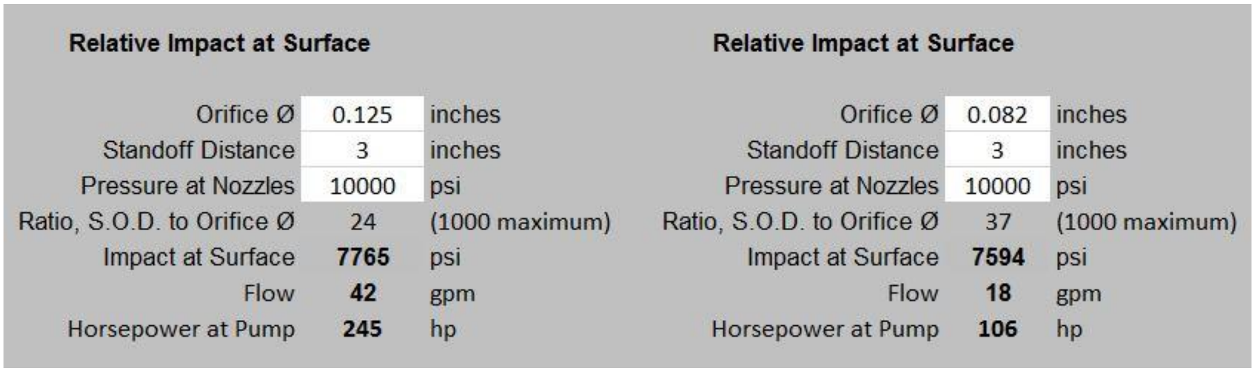
If this same approach is applied to the original calculation comparison from Figure 2, in this case adding a "flow factor" which would represent the slope ratio and applying it to the difference in flow between the two estimations, a relative comparison of jet impact that includes flow rate could be made, as shown in Figure 15.

4. CONCLUSIONS

The purpose of this testing was to determine the effect that the inside diameter of a tube feeding a waterjet nozzle has on jet quality, as well as to determine if there was a relationship between the inside diameter and the overall length of the tube. The results show a dependent relationship between the orifice size, the inside diameter, and the length of the feeder tube. Performance gains due to feeder tube length can be on the order of 50 to 60%, while performance gains due to optimization of the inside diameter of the feeder tube relative to the orifice size can be on the order of 20 to 30%. In shorter feeder tube lengths combined with larger orifice sizes, the optimum inside diameter may be as low as 5 to 7 times the orifice size, while increasing the length of the feeder tube shifts the optimum inside diameter into a range of 7 to 13 times the orifice size.



Jet Performance Deterioration with Standoff Distance, Equation 1 from Middle Curve
Figure 1.



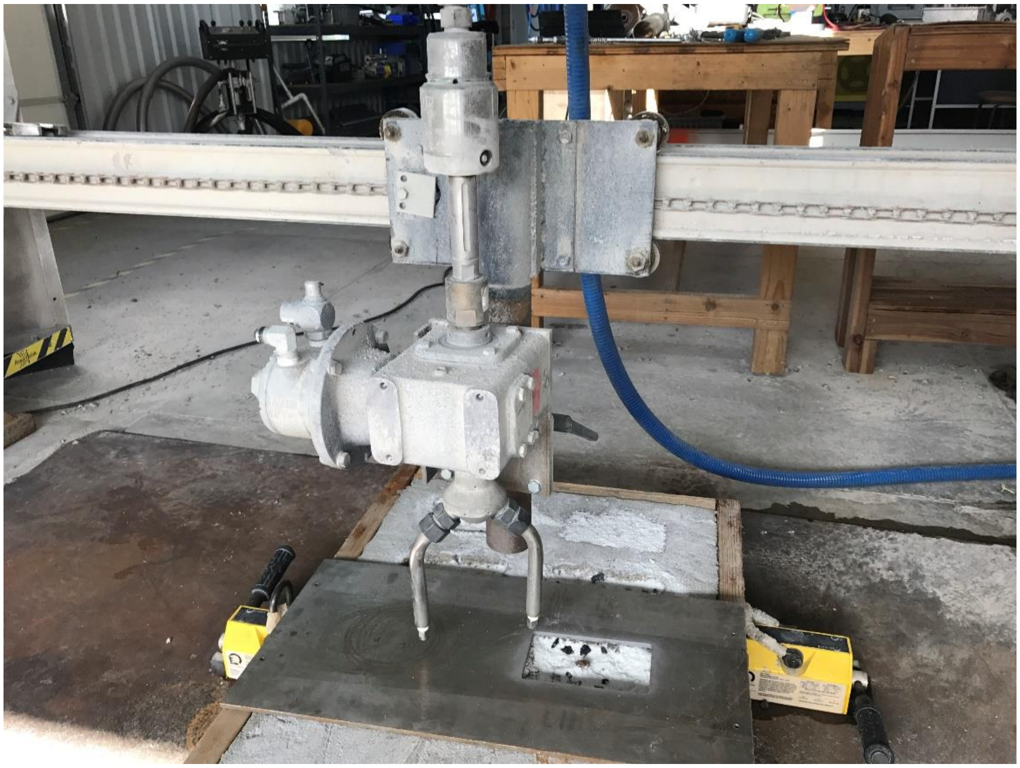
Relative Impact at Surface

Orifice Ø	0.125	inches
Standoff Distance	3	inches
Pressure at Nozzles	10000	psi
Ratio, S.O.D. to Orifice Ø	24	(1000 maximum)
Impact at Surface	**7765**	psi
Flow	**42**	gpm
Horsepower at Pump	**245**	hp

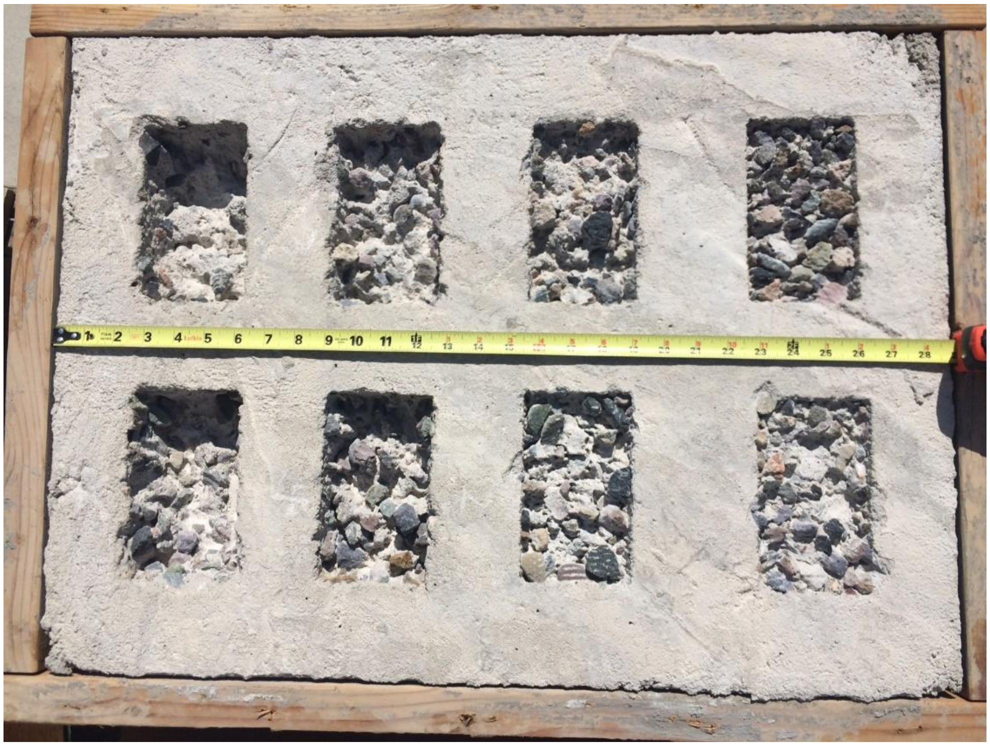
Relative Impact at Surface

Orifice Ø	0.082	inches
Standoff Distance	3	inches
Pressure at Nozzles	10000	psi
Ratio, S.O.D. to Orifice Ø	37	(1000 maximum)
Impact at Surface	**7594**	psi
Flow	**18**	gpm
Horsepower at Pump	**106**	hp

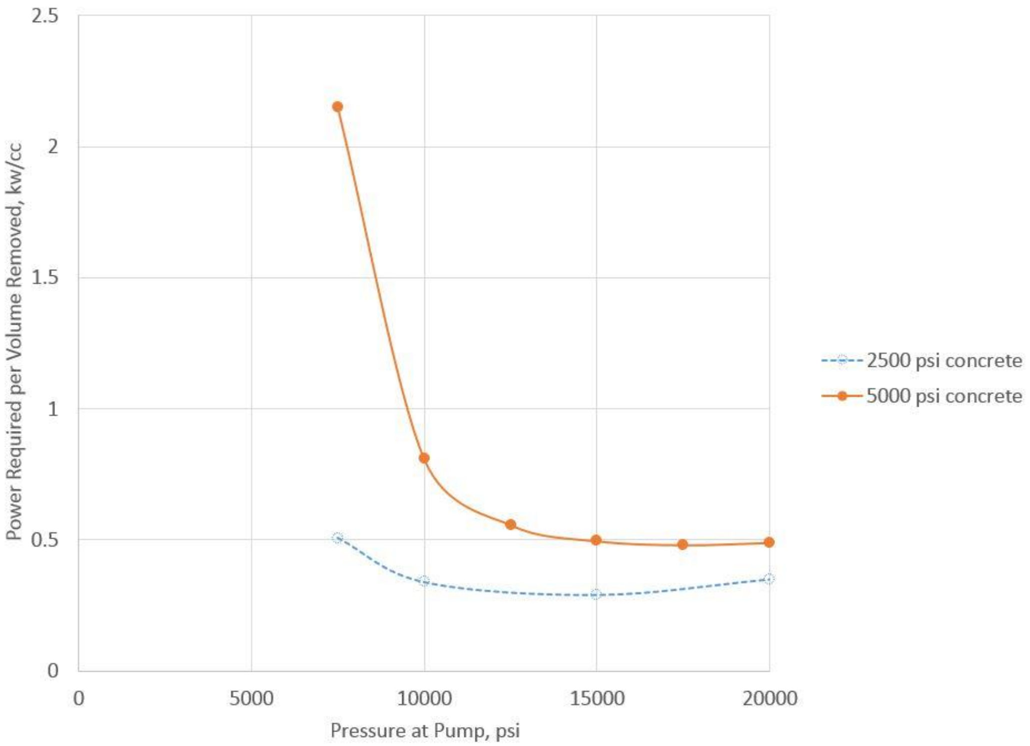
Comparing Jet Impact at Surface as based on Standoff Distance Deterioration Curve Relative to Orifice Size
Figure 2.



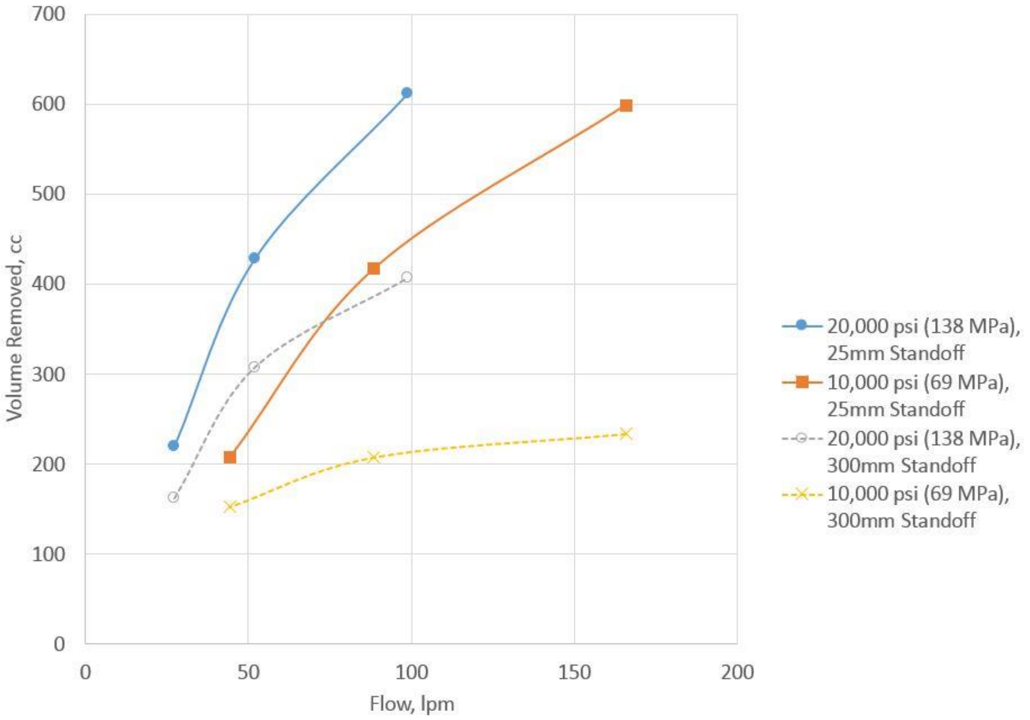
Test Arrangement Consisting of Rotating Jet Head and Traverse Mechanism
Figure 3.



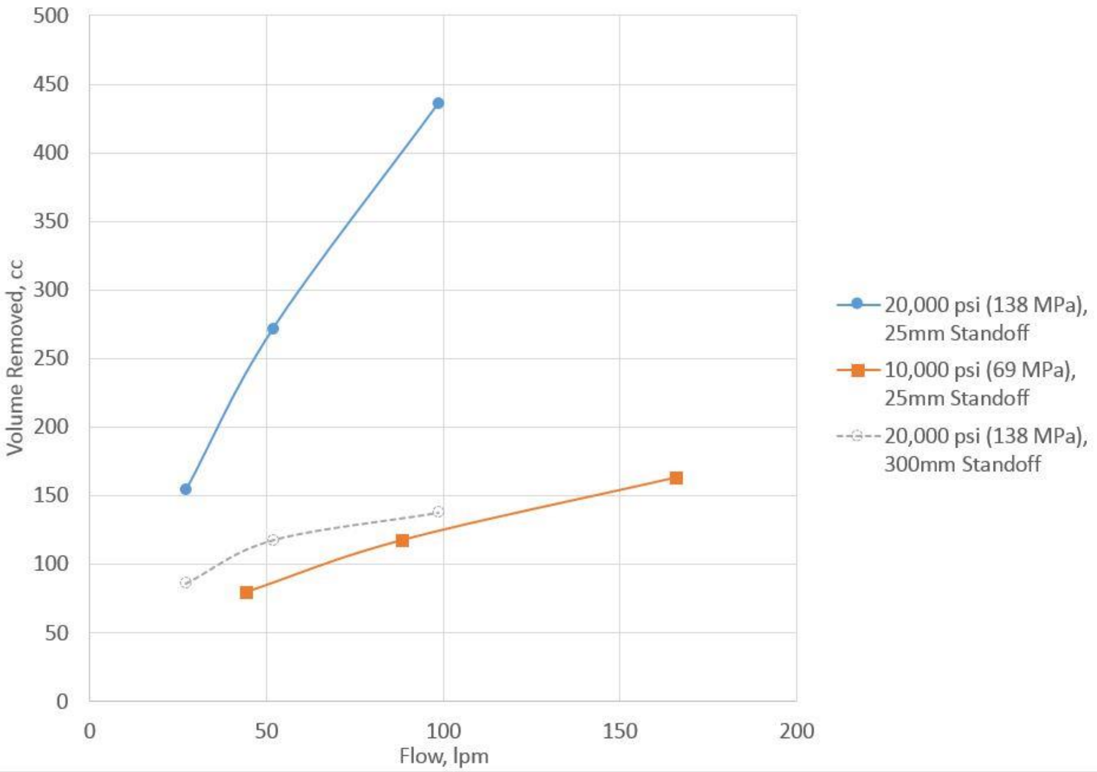
Concrete Test Sample after Completion of Various Tests
Figure 4.



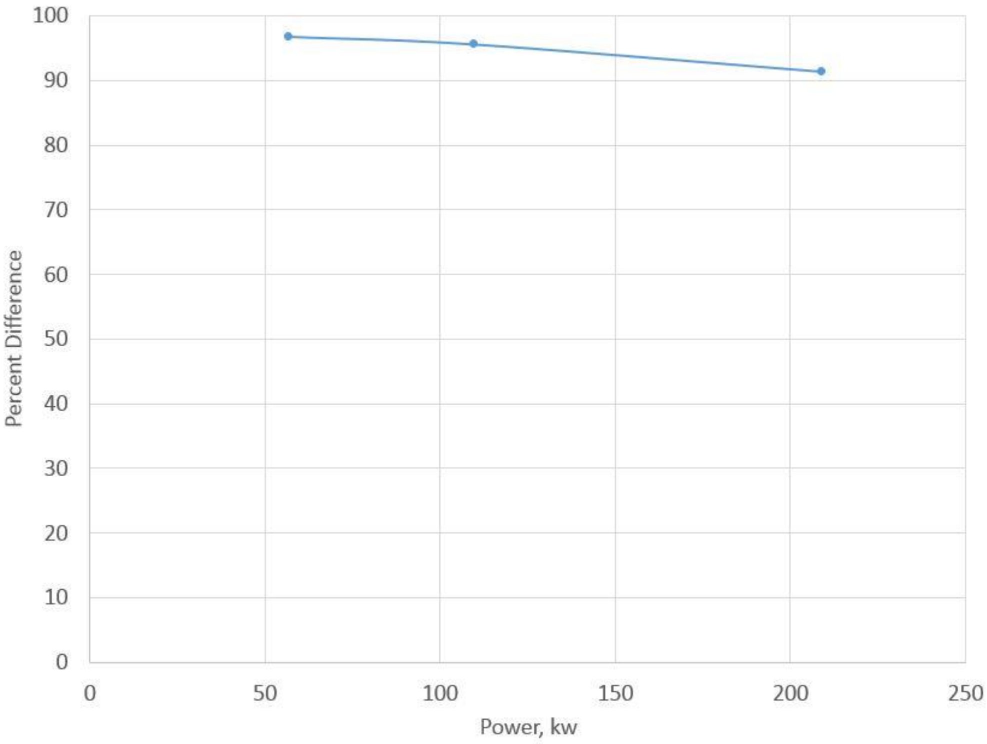
Efficiency of Material Removal Relative to Pressure at the Pump for 2500 psi (17 MPa) and 5000 psi (34 MPa) Concrete Samples
Figure 5.



Volume Removed in 2500 psi (17 MPa) Concrete with Increasing Flow Rate
Figure 6.



Volume Removed in 5000 psi (34 MPa) Concrete with Increasing Flow Rate
Figure 7.



Two Jet Performance as a Percentage of Single Jet Performance
Figure 8.