2013 WJTA-IMCA Conference and Expo
September 9-11, 2013 • Houston, Texas

Paper

IMPACT FORCE OF HIGH PRESSURE WATERJETS

D. Wright
StoneAge, Inc.
Durango, Colorado, U.S.A.

ABSTRACT

One mechanism of a waterjet to penetrate or remove a material is the force of impact produced by the velocity and mass of the water reaching a surface. The mechanisms by which a material is cut or removed by a high pressure waterjet are also dependent on material properties. A number of past tests have been conducted to determine and express the performance of a waterjet on particular materials. This paper presents the results of testing performed to measure the impact force of a waterjet as varied by jet quality, standoff distance, pressure, and flow rate. This data is then compared to past performance results obtained in various materials to determine the relationship of the force of impact to the overall performance in material removal.

Organized and Sponsored by WJTA®-IMCA®

1. INTRODUCTION

The impact force of a high pressure waterjet is a product of the mass of the water and the velocity at which it is moving when it strikes a surface. For this study, testing was conducted to measure the impact forces produced and determine the rate of deterioration of the impact force with increasing standoff distance.

This paper presents the results of this testing, a calculation to estimate the impact force, and a comparison of impact force to material removal effectiveness dependent on standoff distance.

2. TEST ARRANGEMENT

The test apparatus consisted of an impact plate mounted to a load cell, at which a high pressure waterjet stream was directed. The distance between the orifice exit and the impact plate was varied to obtain measurements at standoff distances proportional to the orifice size, from 50 to 1000 times the orifice diameter. Flow rate and pressure were also recorded during the force of impact testing. The nozzle type used in all tests was a round carbide orifice, with a flow straightener located behind the insert.

The effects on impact force with good and poor upstream conditions (illustrated in Figure 1) feeding the jet orifice were also tested, because the quality of upstream conditions has been shown to determine the rate and ability of a waterjet to remove material.

3. TEST RESULTS AND ANALYSIS

3.1 Impact Force

Impact force results for a jet with good upstream conditions versus standoff distance are shown in Figures 2, 3 and 4, for three orifice sizes at pressures of 69, 103, and 138 MPa (10,000, 15,000, and 20,000 psi.)

The impact force at a standoff distance of 50 times the orifice diameter was found to be 20 to 35 percent greater than a calculation of velocity multiplied by mass flow rate, Equation 1 below. This is the same equation used to calculate the reaction force produced by a waterjet.

$$\text{Force (pounds)} = .052 \times \text{Pressure (psi)}^{1/2} \times \text{Flow (gpm)}$$

Equation 1.

In Figure 5, the measured values taken at 50 times the orifice diameter at 69 MPa (10,000 psi) with good upstream conditions are compared to calculated values using the measured flow rate and orifice size to calculate the pressure for use in Equation 1. The standoff distance of 50 times the orifice diameter was the closest standoff distance tested, as it is not common for actual working distances to be much closer.

3.2 Upstream Conditions

The measured impact forces with good and poor upstream conditions were averaged and taken as a percentage of the impact measured at 50 orifice diameters with good upstream conditions, the results of which are shown in Figure 6. Through a standoff distance of 500 diameters, the difference in impact between good and poor upstream remained at 10 percent, before varying further to 20 percent at 1000 diameters.

An analysis of the pressures and flows recorded showed that a given nozzle orifice behaved the same in terms of flow rate and pressure regardless of upstream conditions. Therefore, the reduced force of impact with poor upstream conditions was not a result of a pressure loss or a change in the coefficient of discharge of the orifice.

When forces of impact are compared to actual performance in material removal, as shown in Figure 7, there is a correlation. The biggest difference occurs with increasing standoff distance, where the material removal performance deteriorates at a greater rate than impact force. The difference between good and poor upstream conditions is also greater in material removal than the measured difference in impact force. These differences could be attributed to loss of velocity of the jet with increasing standoff distance and to the coherence of the jet, which more strongly affect material removal, particularly as the threshold for jet effectiveness in a material is approached.

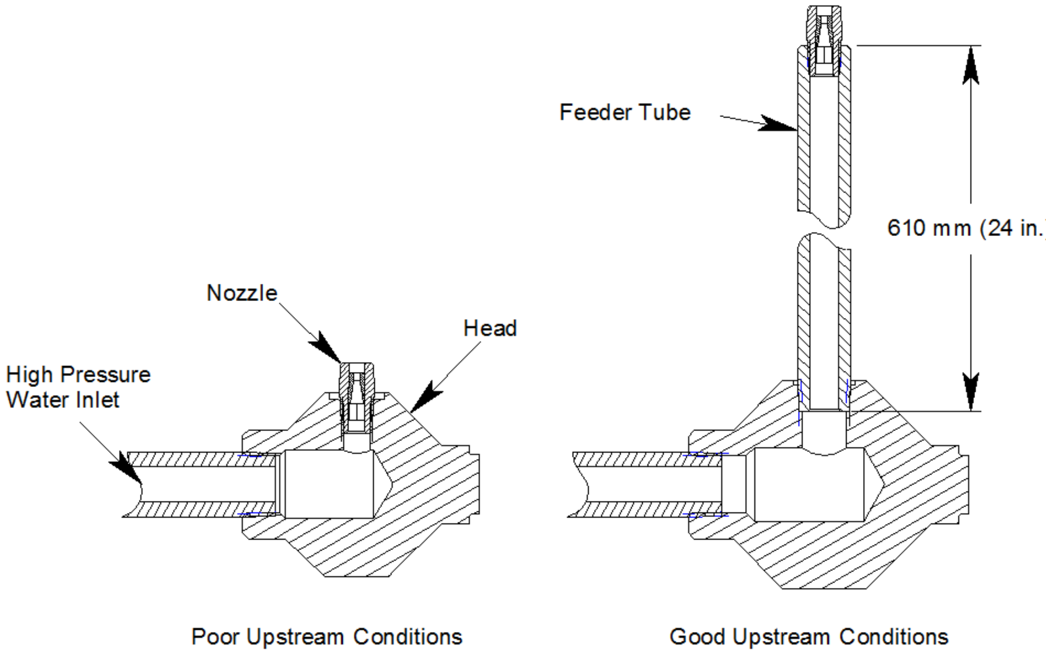
4. CONCLUSIONS

The analysis of the impact forces produced by high pressure waterjets showed them to be proportional to the mass flow rate and the velocity of the jet. When compared to the calculation of reaction force of a jet, the measured impact force at a standoff distance of 50 orifice diameters was between 20 and 35 percent greater. Further study is necessary to determine the reason for the measured value being greater.

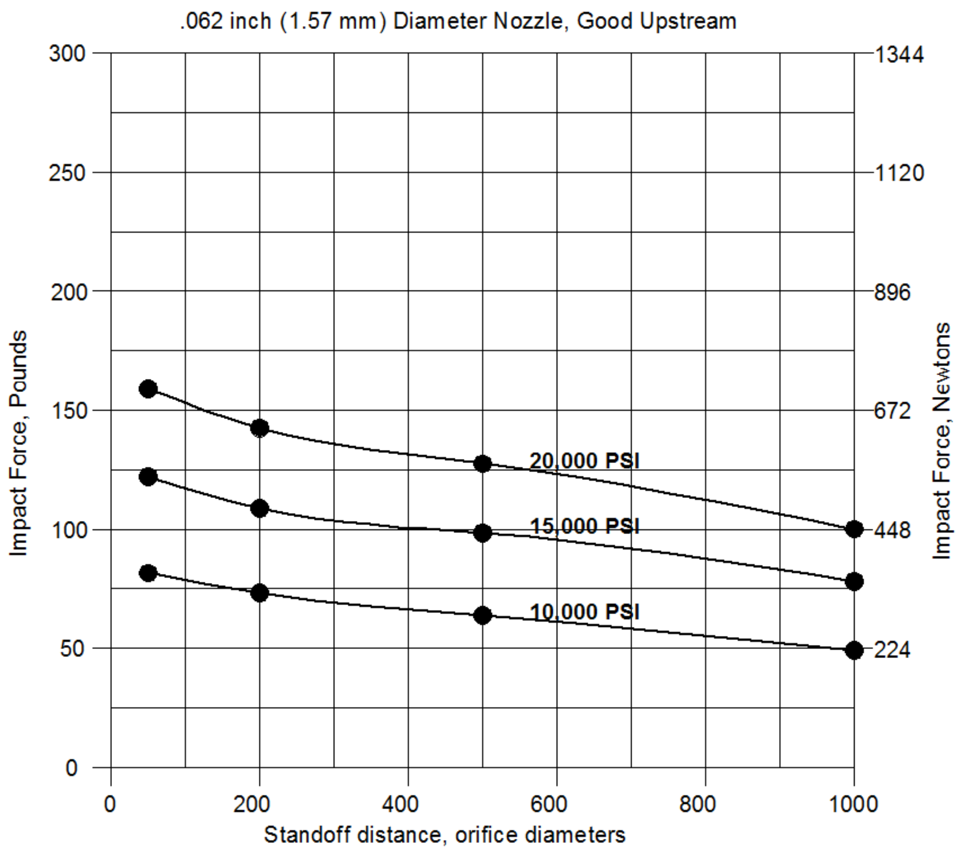
The rate of deterioration of impact force with increasing standoff distance showed a 20 percent decrease at 500 orifice diameters and a 37 percent decrease at 1000 orifice diameters, with good upstream conditions. Poor upstream conditions resulted in an 8 percent less impact at 50 orifice diameters, decreasing to 50 percent at 1000 orifice diameters.

The comparison of impact force to material removal over increasing standoff distance showed some correlation, although the effectiveness in material removal deteriorated at a greater rate than the loss in impact force.

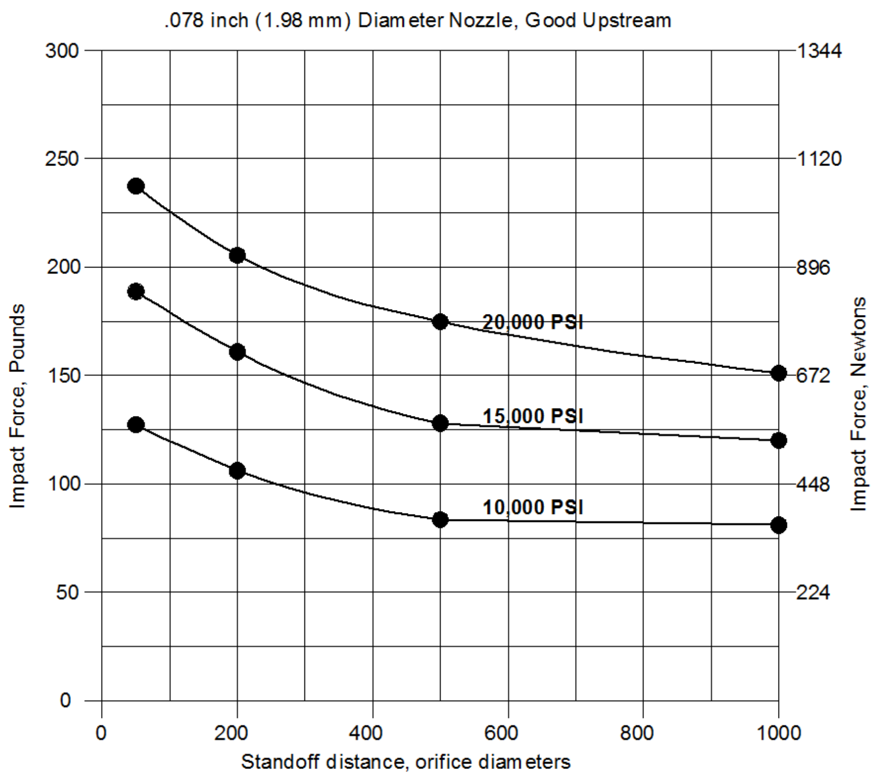
The ability of a waterjet to remove a given material is best determined by direct testing on the material in question, as material properties play the largest role in jet effectiveness. The same impact force can be developed by a jet at 13.8 MPa and 280 lpm (2000 psi and 74 gpm) as a jet at 138 MPa and 87 lpm (20,000 psi and 23 gpm), but the effectiveness of each jet on a given material could be widely different, depending on material properties such as minimum threshold conditions, porosity, grain structure and joints or fractures.



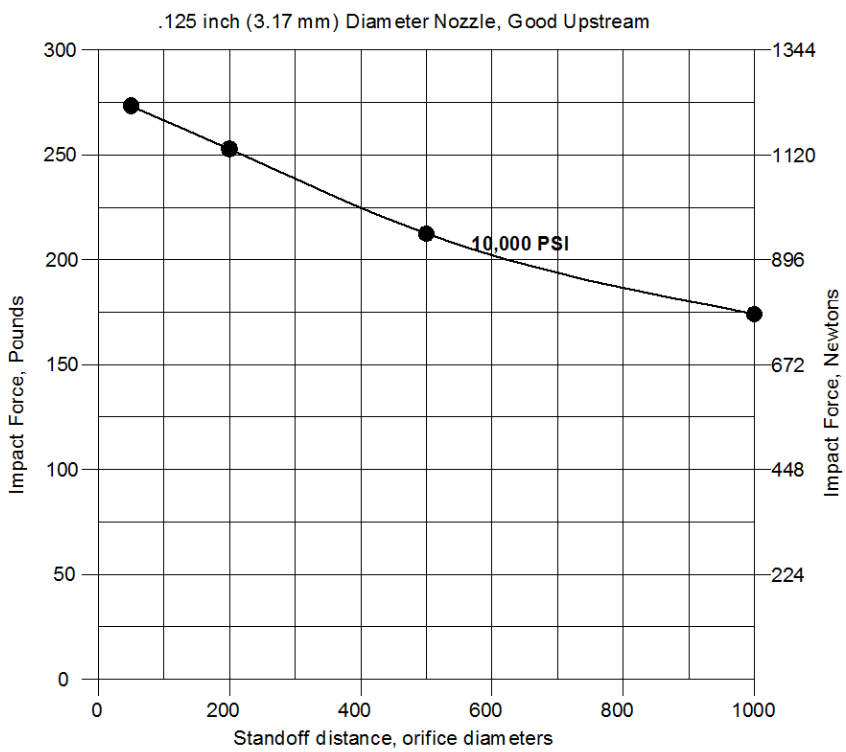
Poor and Good Upstream Conditions Used in Impact Force Testing
Figure 1.



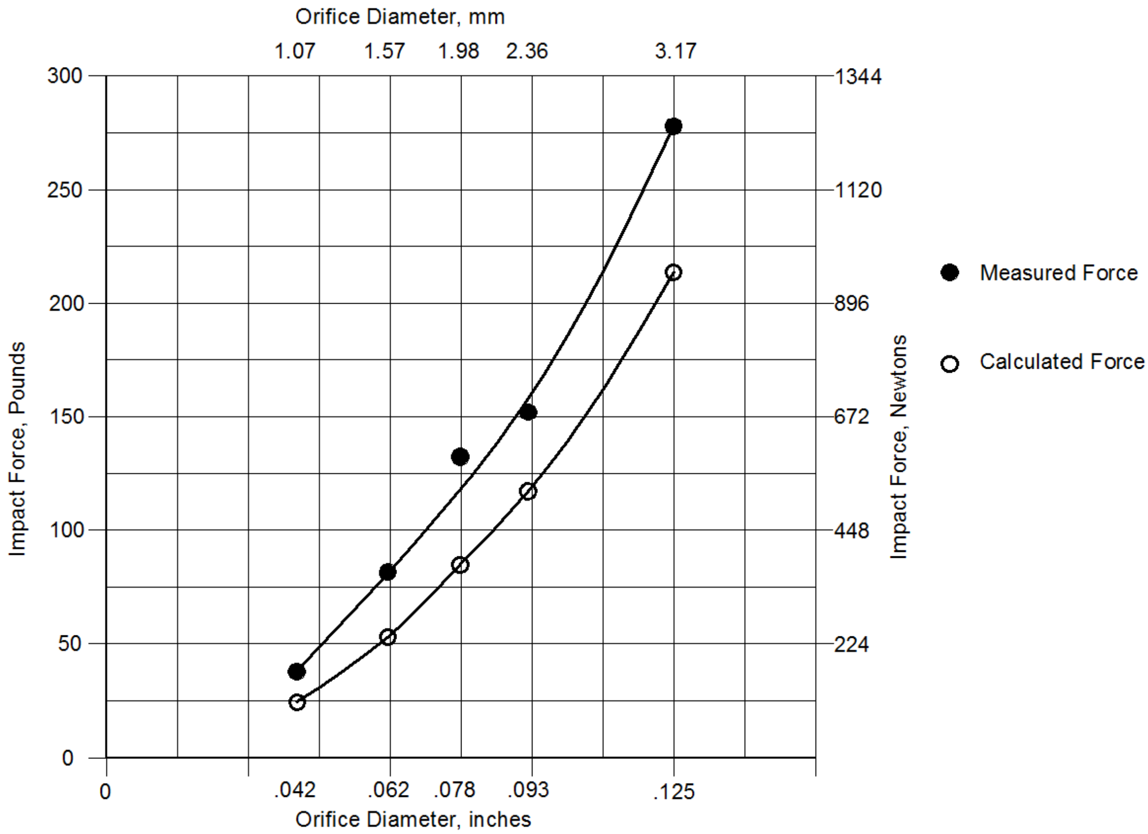
Impact Forces Produced by .062 inch (1.57 mm) Nozzle
Figure 2.



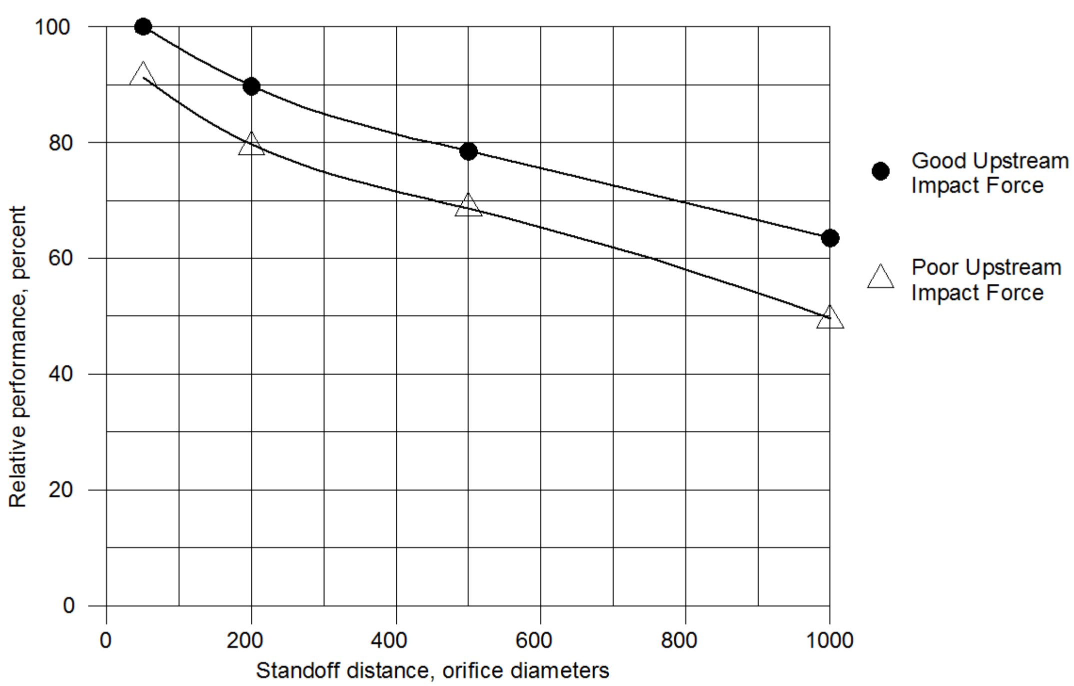
Impact Forces Produced by .078 inch (1.98 mm) Nozzle
Figure 3.



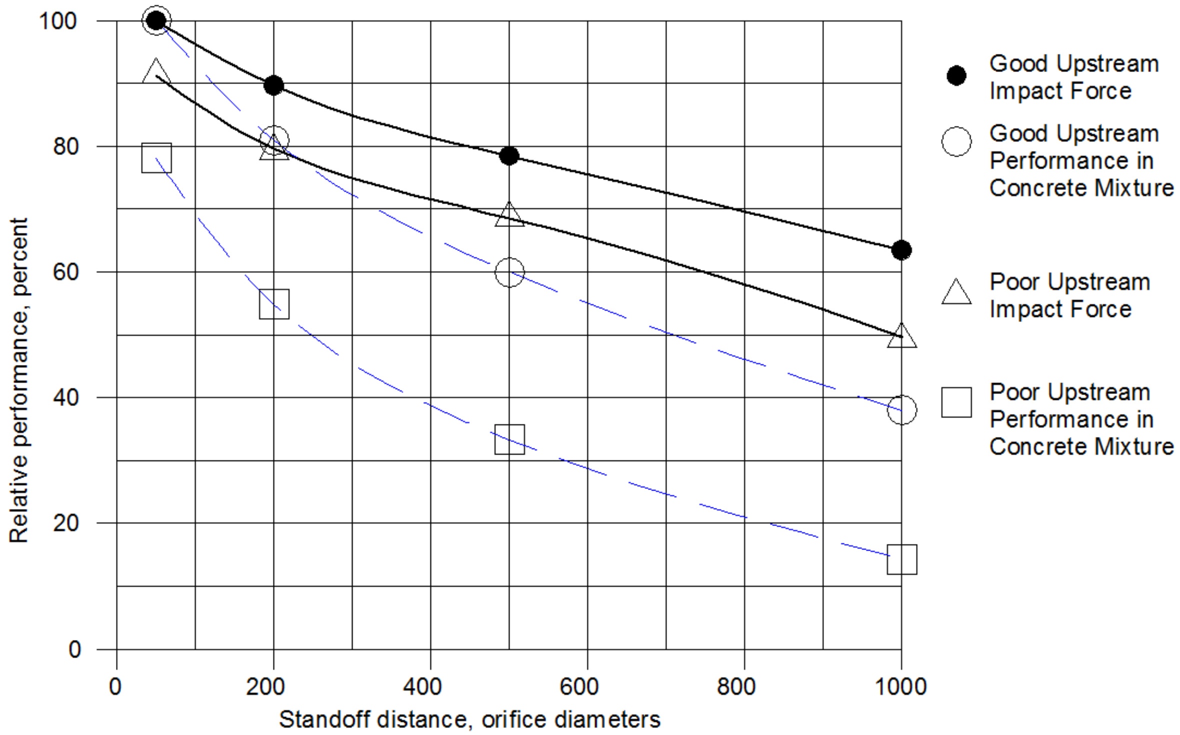
Impact Forces Produced by .125 inch (3.17mm) Nozzle
Figure 4.



Measured Impact Force at 50 X Orifice Diameter Vs. Calculated Force
Figure 5.



Average Impact Force with Good and Poor Upstream Conditions
Figure 6.



Impact Force Compared to Material Removal Performance in Concrete
Figure 7.