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SAFE WATERJET CLEANING OF STEEL PROCESS LINES

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ABSTRACT

Steel process lines and tubes are commonly cleaned using waterjet systems with pressures up to 40,000 psi. There is a risk of damaging these lines depending on operating parameters such as jet pressure, angle, rotation and rate of traverse. These lines vary from small diameter heat exchanger tubes to larger pipes. The highest energy concentrations with greatest risk typically occur in the small diameter tubes. Testing was performed to identify the operating parameters for which no damage would be caused to steel process lines.

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1. INTRODUCTION

Waterjet cleaning of steel tubes, piping and vessels is routinely conducted at pressures from 5,000 to 40,000 psi. The concerns by plant operators have been damage by high pressure waterjets and mechanical wear caused by the rubbing of the nozzle against the wall of the tube. Another sometimes overlooked failure mode of piping and tubing is due to corrosion related to the plant process, in both carbon steel and stainless steel materials. There have been instances of blame placed on waterblast contractors for damage that was actually due to corrosion, because the waterjet cleaning removed the material from the corrosion pits and cracks that had been keeping the tubes from leaking through these tiny pits and cracks. A corrosion damaged stainless steel tube is shown in Figures 1 and 2. The pitting caused by corrosion has relatively sharp edges. A waterjet attacks steel through the process of cavitation erosion by water droplet impact, which looks much more smooth and rounded (see Figures 4, 6, 9, 12, 14 and 15). The purpose of this testing was to determine operating parameters which will not result in waterjet damage to the tubes, and to illustrate what the damage caused by waterjet action looks like.

2. TESTING

Tests were performed using a single fixed jet and multiple rotating jets; Figure 3 illustrates the typical test arrangement for multiple rotating jets. The standoff distances used would be typical of tube and small pipe cleaning but considered relatively close for pipe sizes larger than six inches unless provisions were made to place the jets closer to the pipe wall. For tests performed at and below 140 MPa (20,000 psi), two types of nozzle were used, one being drilled steel of poor quality, and the second high quality stainless steel nozzles with flow straighteners. Tests performed at 250 MPa (36,000 psi) used good quality sapphire nozzles. The tube samples on which the tests were conducted consisted of new 304 stainless steel and 1018 DOM carbon steel, both 1.88 in. inside diameter. The amount and type of damage was found to be quite similar in the stainless steel and the carbon steel, so most of the testing was done in the 1018 carbon steel to allow for better visual contrast. The damage was quantified and compared in terms of depth of material removal.

3. RESULTS

3.1 Stationary Jets

The first of these tests used a poor quality drilled steel nozzle orifice, typical of small tube cleaning nozzles without replaceable inserts. An orifice size of 1.07 mm (.042 in.) was drilled at 90° in the head and tested with the jet perpendicular to the tube wall, at a standoff distance of 9.6 mm (.38 in.) Tests were run on both carbon steel and stainless steel for periods of 10, 30 and 60 seconds at pressures of 70, 105 and 140 MPa (10,000, 15,000, and 20,000 psi). Figure 4 shows the damage created at 140 MPa (20,000 psi) with a drilled jet in carbon steel; the carbon steel results are graphed in Figure 5. Figure 6 is a photograph of the damage created at 140 MPa (20,000 psi) in stainless steel; the stainless steel results are plotted in Figure 7. Note that there is very little difference in results between the two materials. At 70 and 105 MPa (10,000 and

15,000 psi), no damage was caused at the 10 second exposure, while slight damage occurred at 140 MPa (20,000 psi). The damage caused at 70 MPa (10,000 psi) can only be felt as surface roughness rather than depth; after exposure for 120 seconds the damage did not increase.

The next series of stationary jet tests used a high quality steel nozzle with a flow straightener and an orifice diameter of .97 mm (.038 in.), exiting from a nozzle head at 90° to the tube wall. Due to the nature of the cavitation mechanism by which the waterjet damages the tube wall, this more coherent jet did not produce any damage up to or including 140 MPa (20,000 psi) after 60 seconds when the standoff distance was 9.6 mm (.38 in.) from the tube wall. Cavitation and damage did occur when this nozzle was tested with increasing standoff distance at 105 MPa (15,000 psi) for 30 seconds at each point. These results are shown in Figure 8.

The final series of stationary jet tests, conducted at 250 MPa (36,000 psi), used a sapphire nozzle insert, diameter .61mm (.024 in.), tested at 80° to the surface of the tube wall. Results showed that allowing a nozzle operating at this pressure to stop rotating or traversing can result in significant damage to the tube wall. Figure 9 shows the test sample used and the resulting damage. These results are plotted in Figure 10, along with the results at 140 MPa (20,000 psi) from the drilled jet tests for comparison.

3.2 Rotating Jets

Use of rotation as a means of keeping the jet moving over the surface can greatly reduce or eliminate damage to steel tubes and pipes. Figure 11 illustrates the great difference between rotating and stationary jet damage; a stationary jet at 140 MPa (20,000 psi) can cause more damage than rotating jets at 250 MPa (36,000 psi).

Damage by rotating jets will still be incurred if the tool is left rotating in the same place; the amount of time to cause damage is dependent on the pressure. At 70 MPa (10,000 psi) a head rotating 500 rpm with three drilled steel jets of .84 mm (.033 in.) diameter (30 kW) at 85° in the same path, at a standoff distance of 9.6 mm (.38 in.), did not cause any damage after 4 minutes in the same location, and only slight damage had occurred after 6 minutes. With the same conditions at 105 MPa (15,000 psi) and .79 mm (.031 in.) diameter jets (48 kW), no damage was caused after 60 seconds, with slight damage after 120 seconds, and at 140 MPa (20,000 psi) with .79 mm (.031 in.) diameter jets (74 kW), slight damage was caused after 30 seconds. The damage produced at the latter condition is shown in Figure 12. The plotted results are shown in Figure 13 in addition to those obtained from a rotating head at 250 MPa (36,000 psi) with three nozzles, .48 mm (.019 in.) diameter (62 kW) at 80° to the tube wall with 9.6 mm (.38 in.) standoff distance. At 250 MPa (36,000 psi), a small amount of damage was caused after 10 seconds, and a fair amount was created after 60 seconds. Figures 14 and 15 show the test sample used and the resulting damage. When operating at 250 MPa (36,000 psi), even with rotation, the tool should be kept moving along the tube.

3.3 Jet Angle

The effect of jet angle of impingement on the tube wall was studied at 250 MPa (36,000 psi) with rotating jets to determine if a shallow angle resulted in reduced damage. A single .61 mm

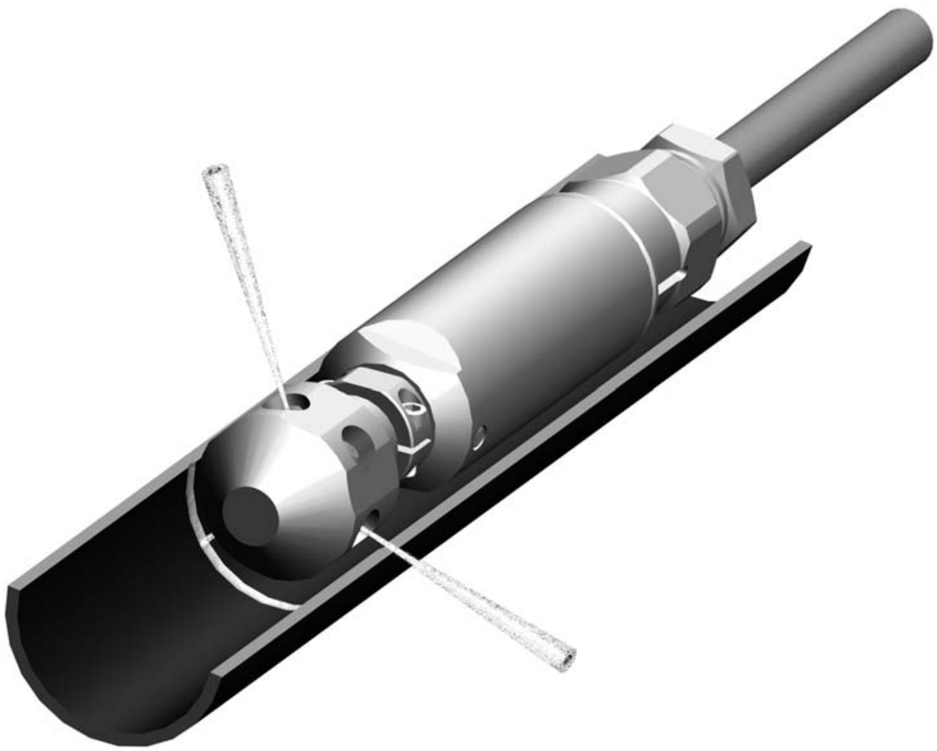
(.024 in.) sapphire nozzle was used. At 10 degrees, no damage occurred after 60 seconds of exposure, but a small amount of damage did begin to occur at 20 degrees after 30 seconds, and after 10 seconds with a 30 degree angle. These results are shown in Figure 16.

4.0 CONCLUSIONS

Waterjet damage to steel tubing and pipe is quite dependent on the operating pressure, rotation or other motion of the jet, and the amount of time the jets are left in the same place. Damage is also dependent on the standoff distance and somewhat dependent on the quality of the jet. There is a fairly high risk of damage at 250 MPa (36,000 psi); the jets must be kept continuously rotating and traversing along the tube or pipe; if the rotation or linear motion stops for as much as 10 seconds, damage may be caused. There is a decrease in risk when the pressure is lowered to 140 MPa (20,000 psi); however, a stationary jet is still likely to cause damage and the operator should not allow a rotating tool to be left in the same place for 30 seconds or more. The risk decreases considerably further at 105 MPa (15,000 psi); rotating jets require over a minute in the same location to begin to create damage, while a stationary jet could cause a small amount of damage after 30 seconds. Operating pressures at or below 70 MPa (10,000 psi) are at very slight risk of causing damage with any combination of conditions.

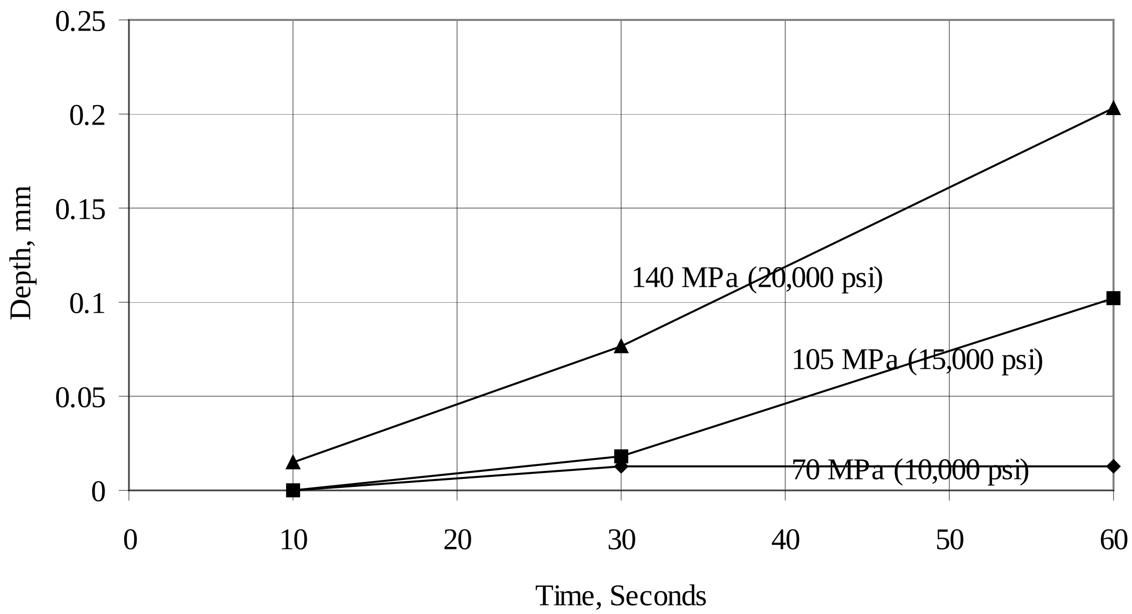
Pitting Caused by Corrosion in Stainless Steel Tube
Figure 1.

Detail of Corrosion Pits in Stainless Steel Tube
Figure 2.

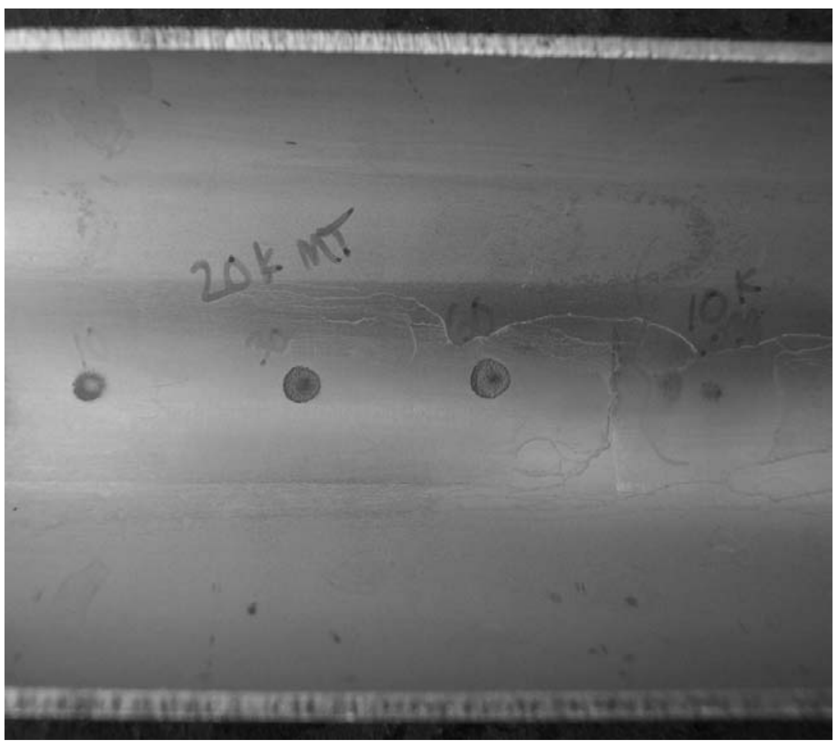


Rotating Nozzle Test Arrangement
Figure 3.

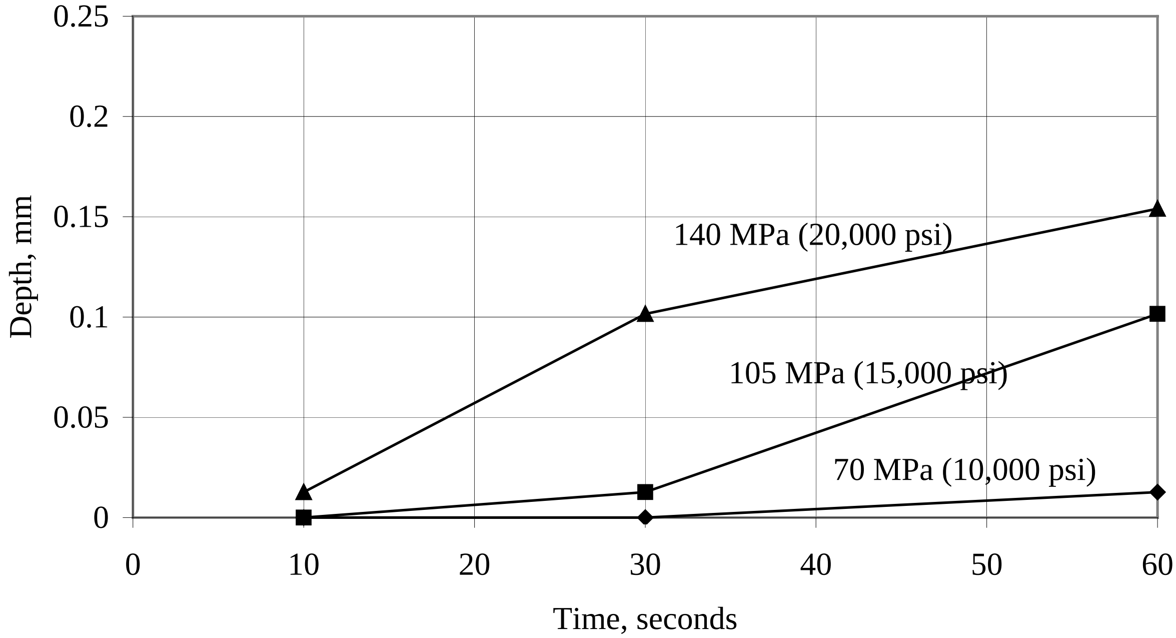
Damage to Carbon Steel Tubing, at 140 MPa (20,000 psi) with Stationary Drilled Steel Nozzle, for Time Periods of 10, 30 and 60 Seconds
Figure 4.



Stationary Drilled Steel Nozzle Damage to 1018 Carbon Steel Tube Wall
Figure 5.

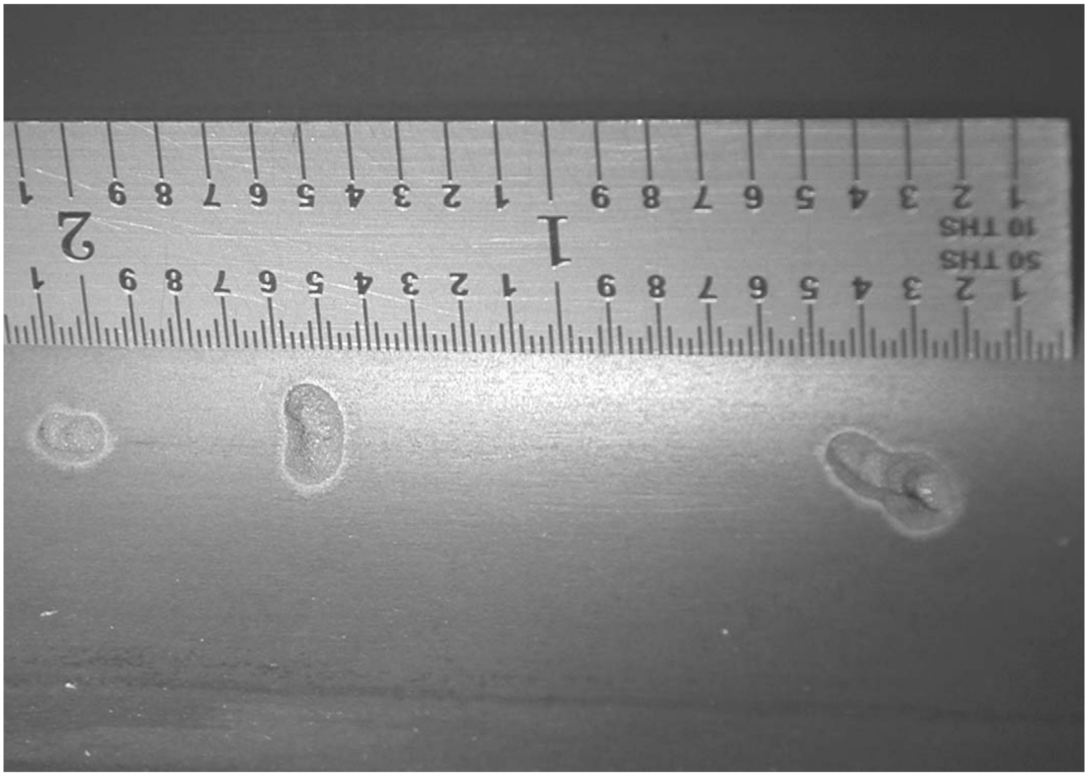


Damage to Stainless Steel at 140 MPa (20,000 psi) with Drilled Steel Nozzle, for Time Periods of 10, 30 and 60 Seconds
Figure 6.

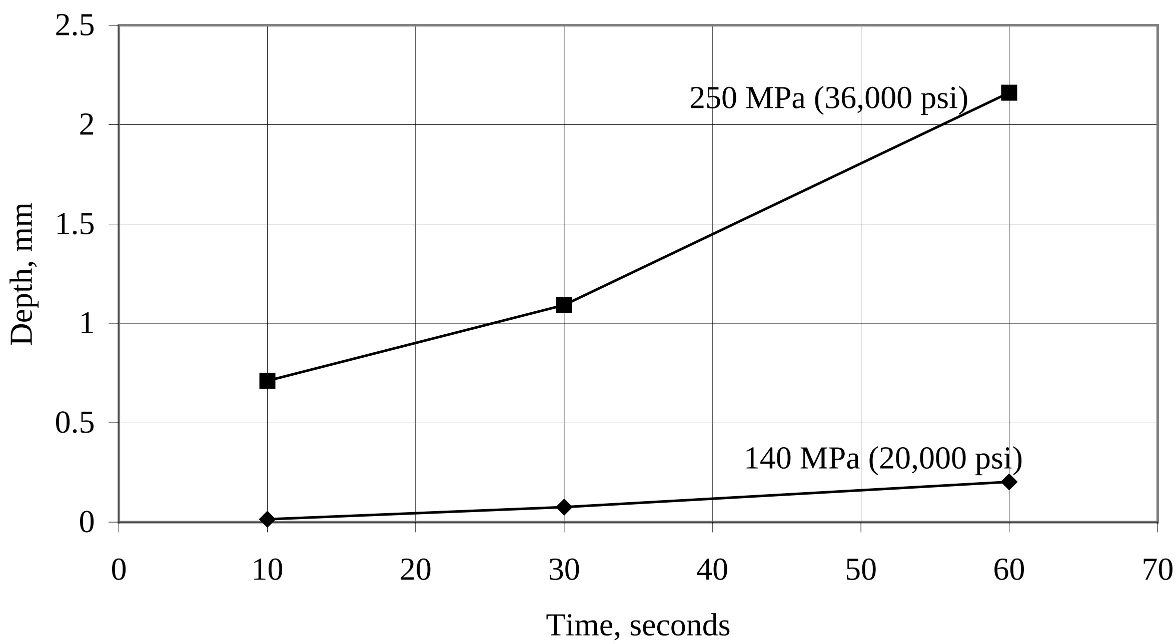


Stationary Drilled Steel Nozzle Damage to 304 Stainless Steel Tube Wall
Figure 7.

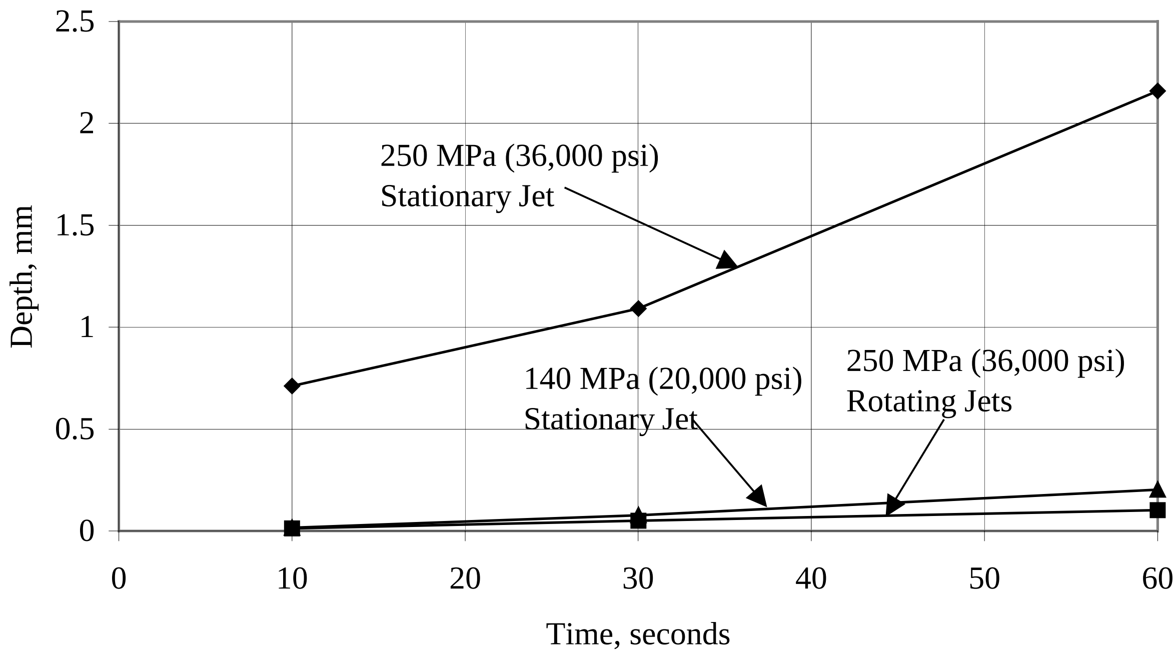
Effect of Standoff Distance with a Stationary High Quality Steel Nozzle
With a Flow Straightener at 105 MPa (15,000 psi)
Figure 8.



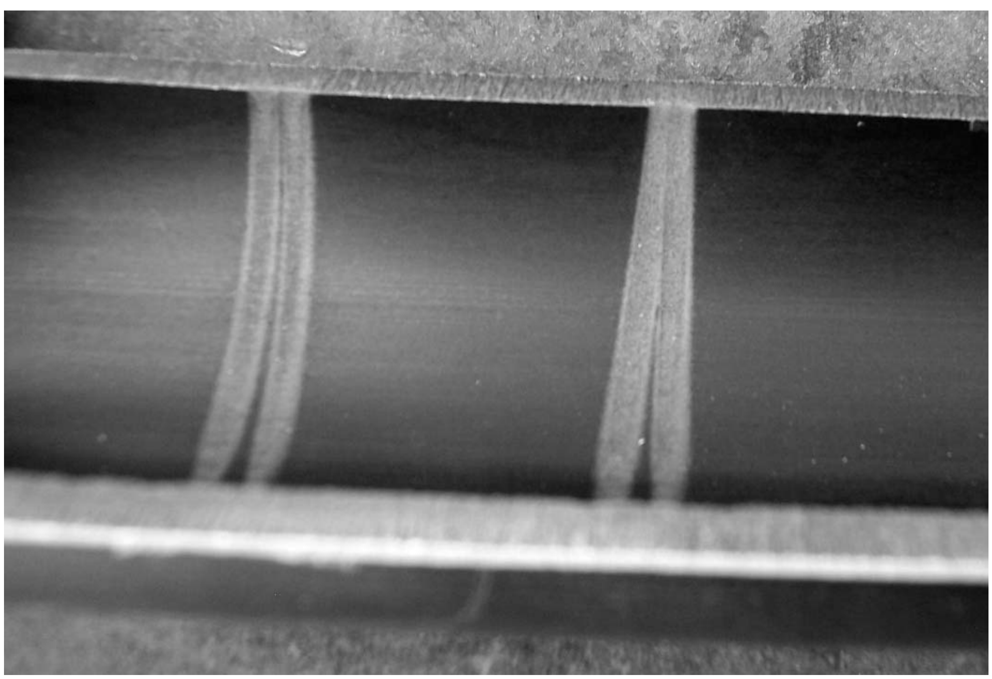
Damage at 250 MPa (36,000 psi), Time Periods of 10, 30 and 60 Seconds
Figure 9.



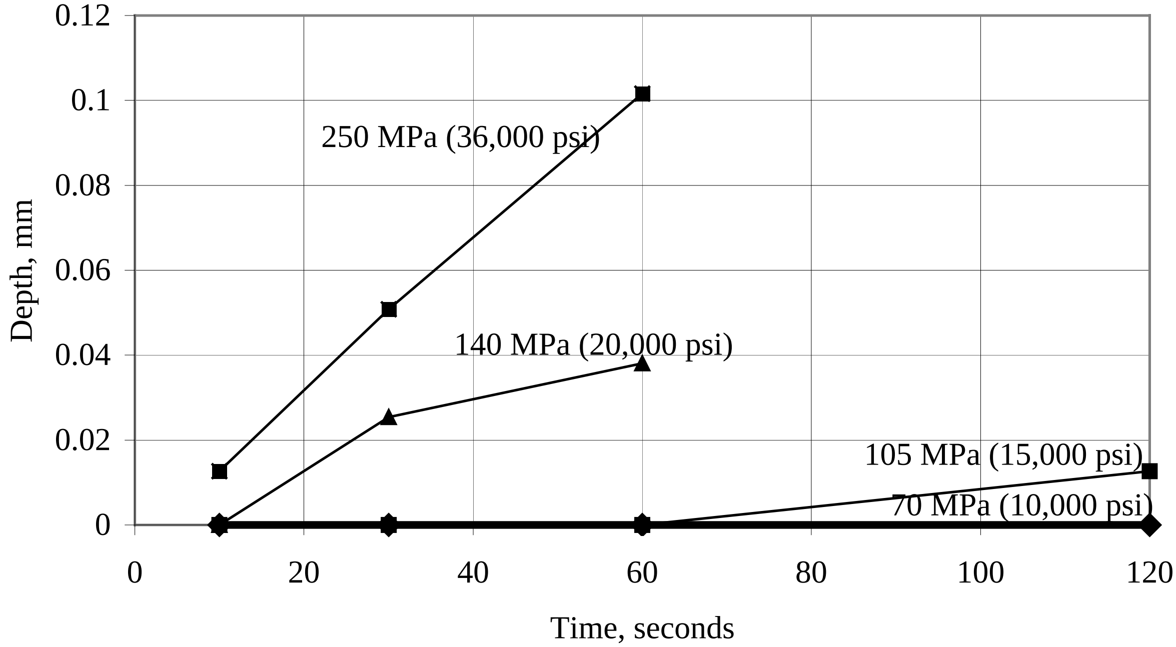
Stationary Sapphire and Drilled Nozzle Damage to 1018 Carbon Steel Tube
Figure 10.



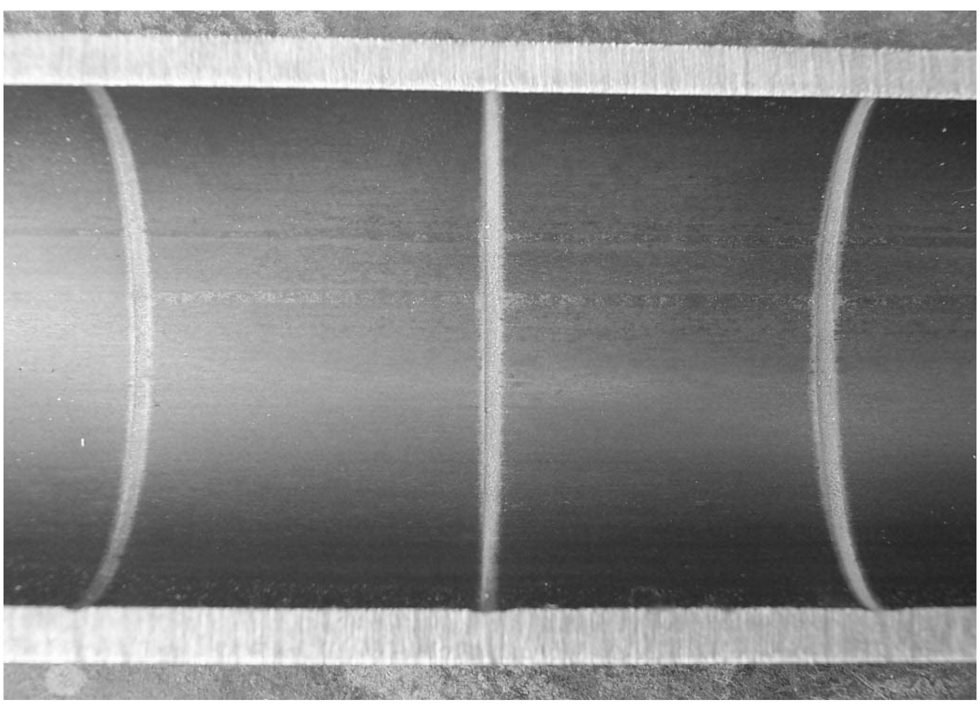
Rotating Jet Damage Compared to Stationary Jet Damage
Figure 11.



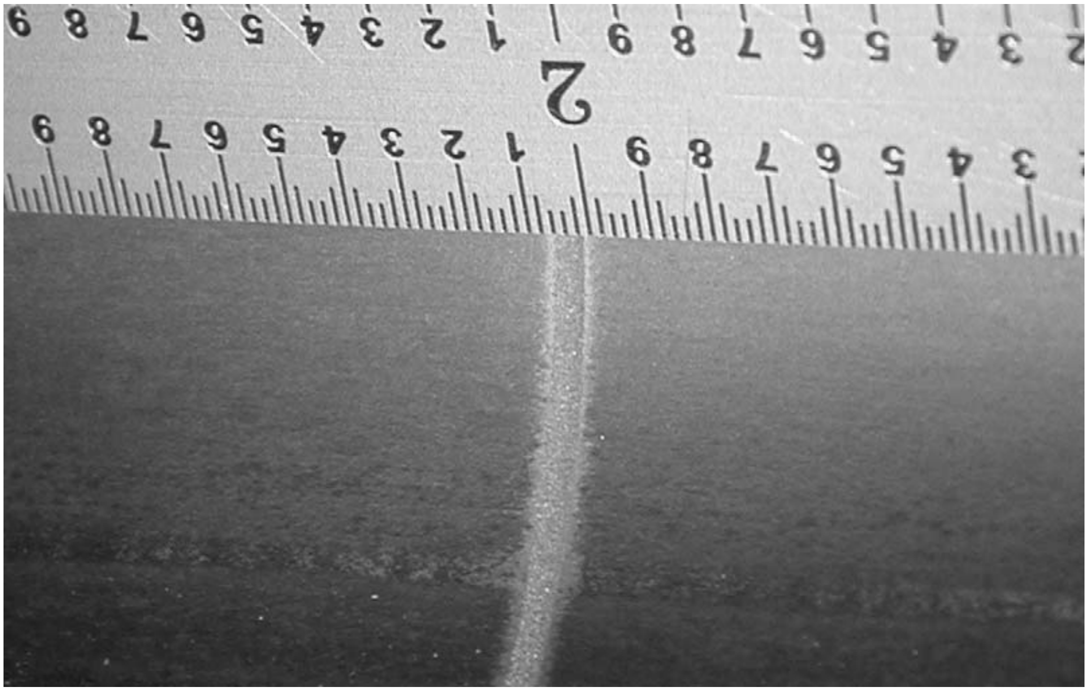
Rotating Jet Damage at 140 MPa (20,000 psi), Drilled Steel Nozzles, Time Periods of 30 and 60 Seconds
Figure 12.



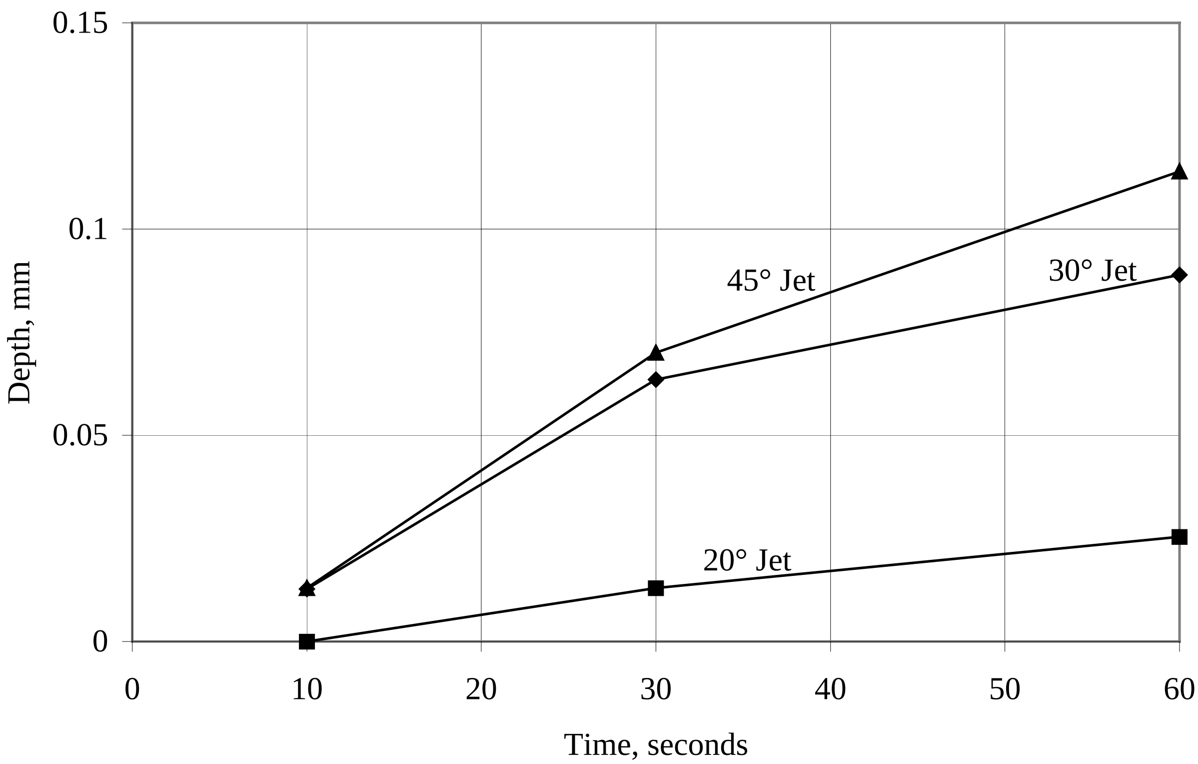
Rotating Jet Damage, Drilled Steel and Sapphire Nozzles
Figure 13.



Rotating Jet Damage at 250 MPa (36,000 psi) at Time Periods of 10, 30 and 60 Seconds
Figure 14.



Detail of Damage by 250 MPa (36,000 psi) Rotating Jet after 30 Seconds
Figure 15.



Effect of Jet Impingement Angle at 250 MPa (36,000 psi) with Single Rotating Jet
Figure 16.