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Paper

WATERJET NOZZLE MATERIAL TYPES

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ABSTRACT

There are three common nozzle material types used in waterjet cleaning: steel, carbide, and sapphire. Each has advantages in certain applications, while having real limitations in others. Jet quality produced and life expectancy are both critical issues for industrial waterblast nozzles. This paper presents the results of lab testing and field analysis to determine the wear rate and failure modes of each material type. Commercially available examples were tested under typical waterblast operating conditions and wear was determined by measurement of orifice size and visual deterioration of the jet quality. Recommendations are given for nozzle material depending on operating conditions.

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1. INTRODUCTION

Nozzles are often the least expensive individual component of a waterblast system, but they can make a difference of two or more times the effectiveness of the most expensive component, the high pressure pump. Initial jet quality of a new nozzle is dependent on the design of the nozzle, and can vary by as much as 60 percent between one type and another.

Through use, all nozzle materials wear and result in deteriorating jet quality and decreasing production rates. Another result of nozzle wear may be decreasing pump pressure; as some nozzle materials wear the orifice size increases, requiring an increase in flow rate to maintain the same pressure. Since waterblast pumps have a fixed output in flow, once their maximum output is reached, the pump pressure decreases as the orifice size increases.

The various nozzle materials wear differently depending on the water quality and chemistry, the operating pressure, and the nozzle design.

2. TESTING

Commercially available nozzles were tested five at a time in a manifold, at pressures between 112 and 126 MPa (16,000 and 18,000 psi). Nozzle orifice size and visual jet quality were compared over operating times up to 40 hours. Tests were conducted with water filtered to 25 micron. Additional information is based on reports from field use.

3. RESULTS

3.1 Carbide Nozzles

Tungsten carbide nozzles are usually considered to be the most durable of all material types. In cases of dirty unfiltered water, they are the most durable. In applications where flow rates exceed 190 lpm (50 gpm) or more, water may not be filtered and these users typically get the longest life from carbide nozzles.

There are conditions where carbide nozzles are not the best type of material to use; at pressures above 10,000 psi and with water filtered to 25 micron or better, the life of a carbide nozzle may be as short as 10 to 20 hours. These nozzles wear by erosion of the material; this wear can be quite uniform, where the orifice size increases uniformly and the nozzle still produces a coherent jet. In these cases, a worn nozzle is defined by being so large that the desired operating pressure cannot be maintained. This problem is most evident with small orifice sizes. For example, if a .7 mm (.028 in.) diameter nozzle is being used, a 0.1 mm (.004 in.) increase in orifice size is a 15 percent change, resulting in a 30 percent change in flow rate. However, if a nozzle size of 2.0 mm (.079 in.) is being used, the 0.1mm increase in orifice size is a difference of only 5 percent in size, causing a 10 percent change in flow rate.

Another failure of carbide nozzles occurs when the erosion does not occur uniformly. There may be a slight change in orifice size, but the big change occurs in the quality of the jet produced. In these cases the evidence of the nozzle being worn is indicated by reduced production rates, with the jet having deteriorated in cutting ability by half or more.

Tungsten carbide is composed of carbide particles cemented together by a binder. Ratios of binder to carbide vary, as well as binder types. Both of these variables affect the toughness as well as the erosion resistance of the nozzle. In our tests, cobalt binder to carbide ratios of 5 percent and 15 percent were tested, and there was a difference in both wear rate and type of wear. The wear mechanism of carbide materials when used as a nozzle material is not well understood; it is likely erosion of the binder, possibly combined with corrosion-erosion.

Figure 1 shows the change in orifice size for the two different carbide types, and Figures 2 and 3 show the jet patterns produced by each type after the tests. The 5 percent binder had a relatively consistent wear around and through the orifice, and is shown in Figure 4. The 15 percent binder did not change in size much but had uneven wear in the form of deep pockets which affected jet quality. Figure 5 shows the effect on pressure with wear of the 5 percent binder carbide nozzle, if the output of the pump's flow rate is constant. Overall, the 15 percent binder material showed the longest life.

De-ionized water will also cause very rapid failure of carbide nozzles. With this type of water condition, the erosion of the orifice size can result in a useful life of less than 10 hours.

3.2 Steel Nozzles

Nozzles made from steel vary widely in design and in quality. They are built as replaceable threaded inserts, or can be made by drilling into a disposable head or bit, as would be used in tube cleaning. Those made as replaceable inserts typically have a better jet quality because the inlet to the nozzle can be formed as desired; holes drilled into a head do not have this option and have the worst quality. The better quality replaceable nozzles usually have longer life as well. With water filtered to 25 micron or better and pressures up to 140 MPa (20,000 psi), properly built steel nozzles can have useable lifetimes of 150 to 200 hours and will outlast carbide nozzles. Figure 6 shows the jet patterns produced after 40 hours by a steel nozzle and two different carbide nozzles. Wear in steel nozzles is defined by degradation of the jet pattern produced; orifice size change does not usually occur.

Steel nozzles wear by two mechanisms: cavitation erosion and abrasive erosion. The rate of cavitation erosion is mostly dependent on the design of the nozzle, while abrasive erosion will occur in all steel nozzles with the presence of abrasive particles in the water. Figure 7 shows a steel nozzle orifice with 50 hours use with recycled, unfiltered water; the wear due to abrasive erosion is very smooth and even. Figure 8 shows a drilled orifice in a head as an example of cavitation erosion in steel. It is rough and uneven, with pockets running across the flow path.

The shape of the inlet to the orifice can affect the rate of cavitation erosion. Figure 9 shows two drilled orifices in a steel head, with the one on the left having a chamfered inlet. Unfortunately, this is often not possible to do, as access to the back side of the orifice is needed to perform this operation. Operating pressure also influences the rate of cavitation erosion; a steel nozzle that might last 150 hours at 140 MPa (20,000 psi) will only last 20 to 30 hours at 250 MPa (36,000 psi).

In the case of the tube cleaning heads, where the nozzles are drilled directly into the head and erosion due to cavitation is the primary mode of failure, life is also dependent on water filtration. Figure 10 shows the average life based on water filtration for heads made of 17-4 stainless steel, at an operating pressure of 70 MPa (10,000 psi).

3.3 Sapphire Nozzles

Sapphire nozzles are most commonly used for operating pressures above 140 MPa (20,000 psi). They produce high quality jets in orifice sizes less than 1 mm (.040 in.) but have poorer quality jets in larger sizes, compared to carbide and good quality steel nozzles. Sapphire nozzles require very clean water, filtered to 10 micron or better. With good conditions, their life can approach 200 hours or more, as the material does not suffer from the erosion problems of carbide or steel nozzles. However, the sapphire material is very brittle, and any tiny chip on the edges of the orifice will destroy the jet quality. Any particles in the water passing through the nozzle will cause these chips, and if a large particle strikes the sapphire it can be instantly cracked. They are also quite easily damaged by rebound of the material being jetted. For these reasons, sapphire is not commonly used in waterblasting operations at pressures below 140 MPa (20,000 psi).

4.0 CONCLUSIONS

There is no single nozzle material that is suitable for all operating conditions. Selection should depend on how well the water will be filtered and on the operating pressure. The nozzle design also has some effect on operating life; the initial jet quality produced is an indication of the quality of the nozzle design. Table 1 lists the nozzle material types discussed in this paper and the recommended conditions for each.

Carbide nozzles outlast all other materials when unfiltered water is used. There are different types of carbide available with variations in type of binder and binder percentage; these factors affect the type of wear and wear rate of carbide nozzles.

Steel nozzles will outlast carbide when water filtered to 25 micron or better is used; this difference in life becomes greater with operating pressures above 70 MPa (10,000 psi). Steel nozzles can wear rapidly with dirty water conditions. The life of a steel nozzle is also dependent on the design of the nozzle; a good design can allow a life of up to 200 hours, while a poorly designed nozzle may have a life of only 40 hours.

Sapphire nozzles require filtration to 10 micron or better to have a reasonable life. They are very fragile, and dirty water can cause instant failure. With properly filtered water, sapphire nozzles can last 200 hours or more.

Recommended Material	Operating Conditions
Carbide	Dirty, unfiltered water; pressures below 140 MPa (20,000 psi)
Steel	Water filtered to 25 micron or better, pressures below 140 MPa
Sapphire	Water filtered to 10 micron or better, pressures above 140 MPa

Table 1. Recommended nozzle materials depending on operating conditions

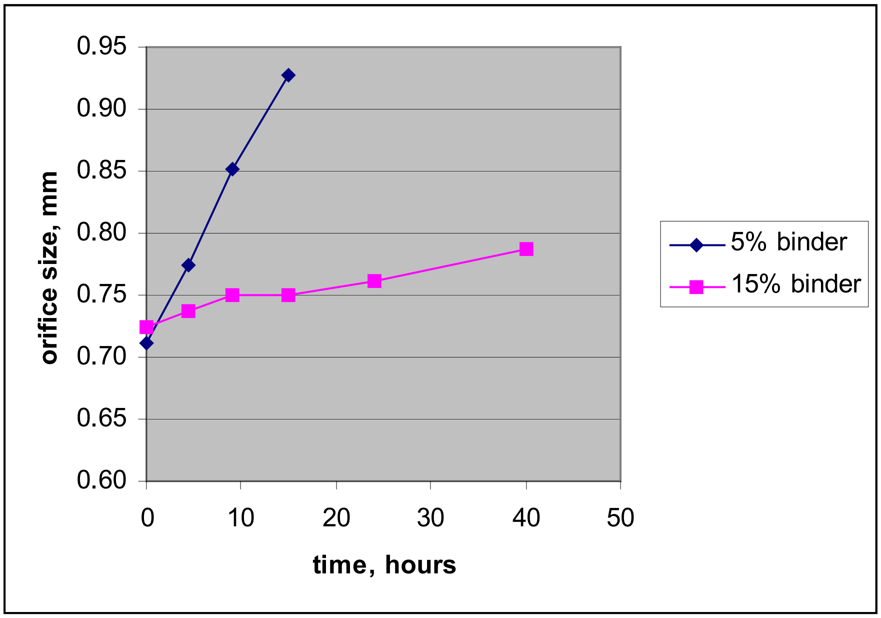

Figure 1. Wear rates in orifice size for two different types of carbide nozzle material

Figure 2. Jet pattern produced by the 5% binder nozzle after 15 hours on the left, compared to new of the same material and design on the right

Figure 3. Jet pattern produced by the 15% binder nozzle after 40 hours on the right, compared to new of same design and material on the left

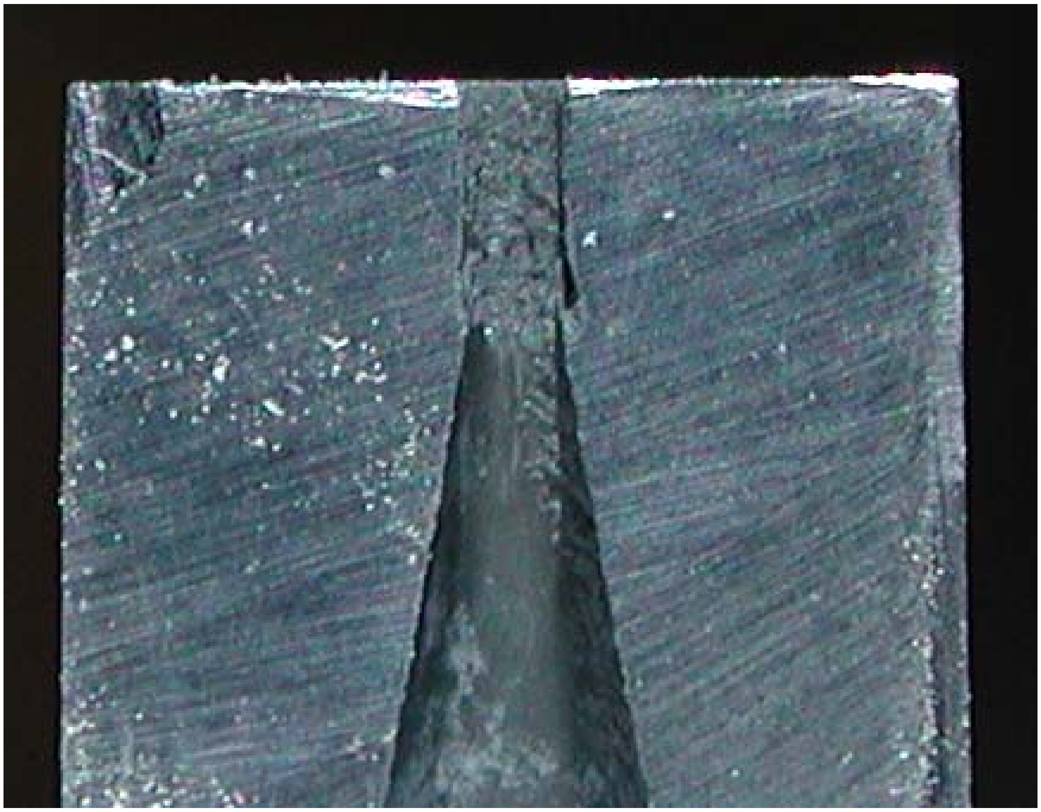

Figure 4. Section of 5% binder carbide nozzle after 15 hours

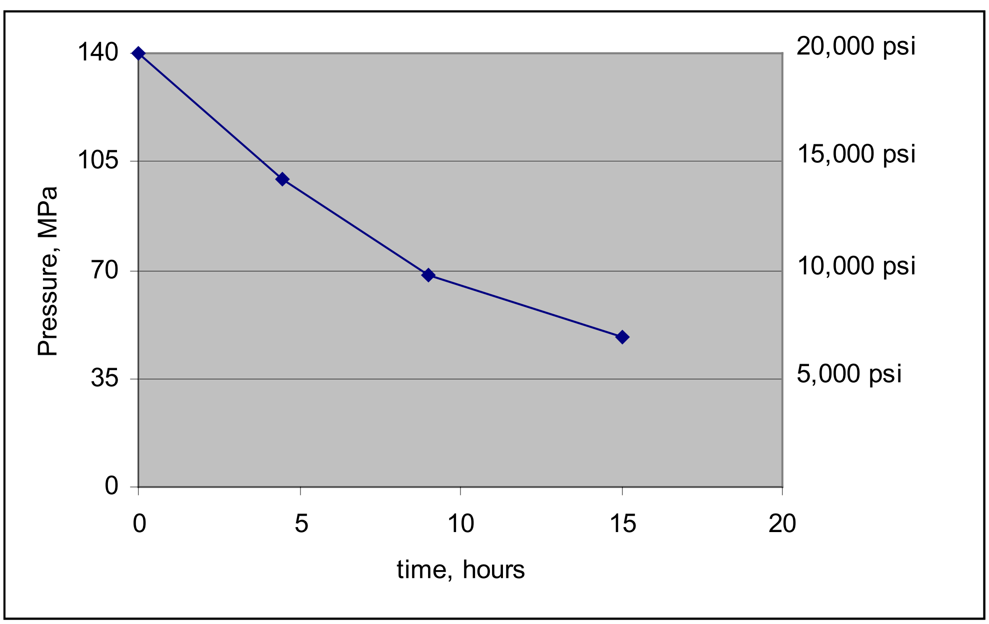

Figure 5. Effect of orifice wear on pump pressure, 5% binder carbide nozzle

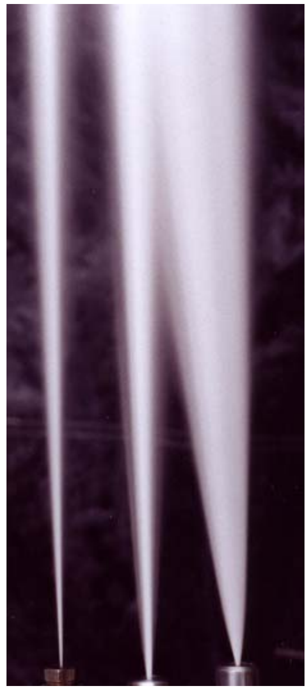

Figure 6. Jet pattern produced by steel nozzle after 40 hours on the left, compared to 5% binder carbide after 10 hours in center, and 15% binder carbide after 40 hours on right

Figure 7. Steel nozzle on the right showing abrasive erosion from very dirty water

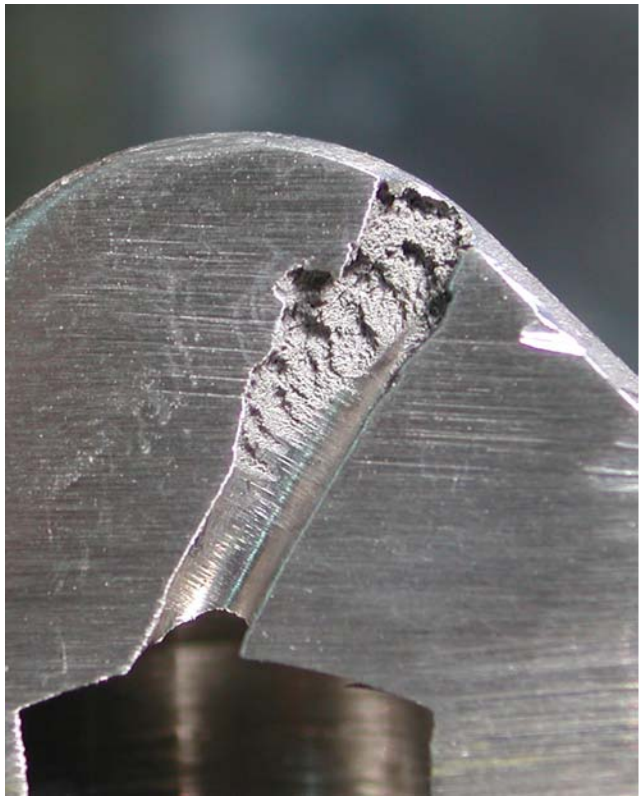

Figure 8. Steel nozzle with cavitation erosion

Figure 9. Steel nozzles, effect of inlet shape to orifice on cavitation erosion

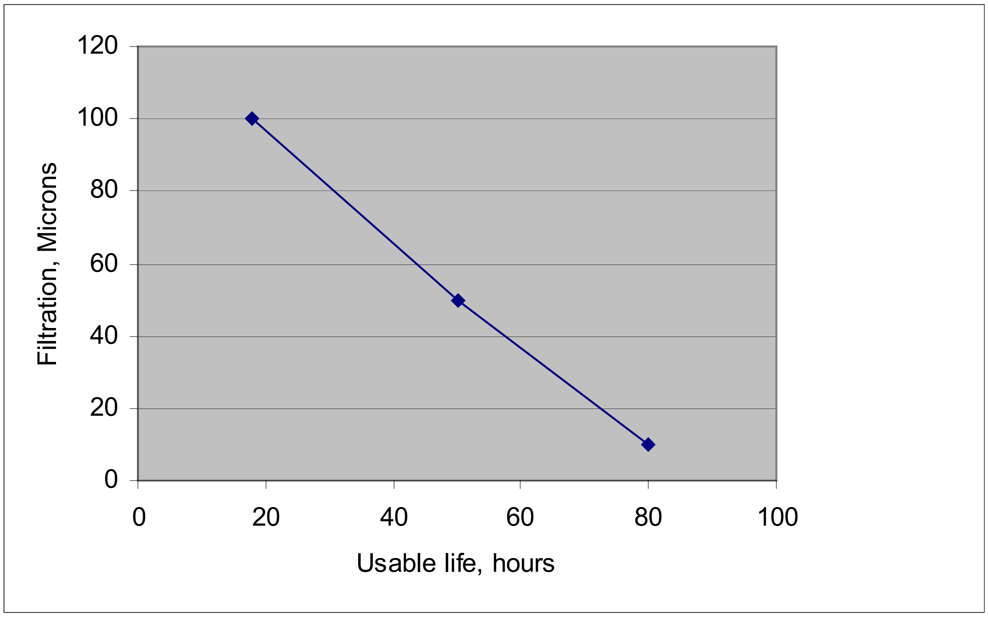

Figure 10. Nozzle life at 70 MPa (10,000 psi), drilled steel nozzle head