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Testing Methods of Cavitation Erosion and the Impact of Component Material Selection on Pump Reliability

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Abstract— This paper presents in detail several cavitation erosion testing methods commonly used in the laboratory. The vibratory cavitation apparatus (G32) is described with its two variants, the direct method using a specimen attached to the vibrating tip of the ultrasonic horn and the alternative method using a fixed specimen facing the horn tip. In the cavitating jet apparatus (G134 and its variants), a jet is discharged at high pressure and velocity in a cell whose pressure may be controlled to adjust the cavitation number. This results in a shear type cavitation whose aggressiveness may be enhanced by a proper design of the nozzle shape and piping assembly. A high-speed cavitation tunnel equipped with a radial divergent test section is also presented. This particular test section generates an unsteady cavity attached to the nozzle exit with cavitation erosion damage concentrated in the cavity closure region. Usual testing procedures together with typical erosion patterns and mass loss results obtained in such facilities are also presented.

Key words: Corrosion, Erosion, Testing, Pump, Reliability, Apparatus, Cavitation, ASTM

I. INTRODUCTION

Proper evaluation of new materials for their resistance to cavitation erosion requires a comprehensive effort addressing both the intensity of the cavitation field and the resistance of the material. In the absence of historical data on the performance of a new material in the target cavitating flow fields, experimental studies in the laboratory offer a convenient means of assessing the cavitation erosion performance.

Field erosion studies have been conducted for hydraulic turbines and pumps (e.g. [1–5]), but for marine applications, small scale laboratory tests are more common. These laboratory experimental studies aim at obtaining within the required short time periods an evaluation of the cavitation resistance of the new material, whereas in the real field cavitation erosion may occur after a long duration of exposure.

Such accelerated erosion test techniques include the utilization of ultrasonic vibration devices to generate the cavitation [6–8], cavitation flow loops with strong flow separation, vortex or venturi effects [9–11], rotating discs and submerged cavitating jets [12–15], and other methods. There are also attempts to test model propellers in water tunnels [16].

Some of these techniques are standardized and follow the American Society for Testing and Materials (ASTM) Standards [17]. The ultrasonic technique and the liquid jet technique are the two most popular laboratory techniques for testing cavitation erosion characteristics of materials.

In this paper, three different laboratory testing methods and equipments are presented in detail, and are used to generate the erosion data presented in Part 1 of this book. They are vibratory devices (ASTM G32), cavitating liquid jets (ASTMG134), and a high-speed cavitation tunnel.

II. VIBRATORY CAVITATION APPARATUS (ASTM G32)

In ultrasonic cavitation tests, the cavitation is generated by a vibratory device employing a magnetostrictive ultrasonic horn (Fig. 2.1). The high frequency oscillations of the horn, typically tens of kilohertz, induce cyclic formation of very high and very low pressures, which generate high negative tension in the liquid.

This can be understood easily if one considers the acoustic field generated by the imposed amplitude motion of the tip of the horn given by:

X (t) = A cos (2*pie*f*t)

Where X (t) is the vertical position of the tip of the horn at instant t, A the amplitude and f the frequency of the tip vibratory oscillations.

The resulting acoustic pressure is given by:

$P = p_1 c_1 X = -2*pie*f*p_1*c_1*A \sin (2*pie*f*t)$

Where p_1 is the liquid density and c_1 is the sound speed in the liquid.

Typically, the vibratory device operates at 20 kHz and the amplitude of the horn tip motion, A, is maintained at 25 lm with the help of a bifilar microscope.

This gives for water:

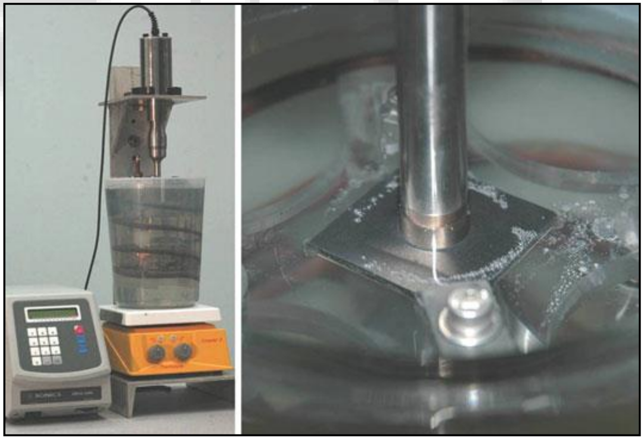


Fig. 2.1:

Ultrasonic cavitation erosion test setup at DYNAFLOW. The ultrasonic horn tip vibrates at 20 kHz and generates cavitation bubbles around the tip. The right picture shows the alternative G32 configuration. The sample is placed in the square support plate below the cylindrical horn. The reddish tip is the Titanium ‘‘button’’. Cavitation under the horn is difficult to see as it is limited to the gap between the ‘‘button’’ and the sample. The white spots are bubbles generated by the vibrations at the free surface of the container and at the periphery of the sample holder

$$P = -4.7 \times 10^6 \sin (2*pie*f*t)$$

Since the amplitude of the pressure oscillations is much larger than the ambient pressure (actually 47 atmospheres), this results in pressure drops during the negative pulse cycle much below the critical pressure of most liquids (see Sect. 1.1.3).

A sample ‘‘button’’ of the material being tested is affixed to the end of the horn and is subjected to the cavitation resulting from the vibration of the horn. A hemispherical cavitation cloud forms at the exposed face of the sample and executes severe dynamics resulting in bubble cloud growth and collapse. The ASTM G32-09 [17, 18] specifies the sample diameter, 16 mm, the vibration frequency, 20 kHz, and amplitude, 50 lm peak-to-peak, and the shape and size of the container in order to minimize variations among different tests and laboratories due to acoustic interaction between transducer and container. A 2,000 ml beaker filled with distilled water and with the tip of the horn submerged 8 mm beneath the free surface is required. In addition, the temperature is controlled by immersing the beaker in a water bath maintained at 25 ± 2 _C.

In an ‘‘alternative’’ G32 test configuration [12, 19] (also known as the stationary specimen method), a stationary material sample is placed at a small distance, typically 0.5 mm, below the vibrating horn tip made of a cavitation resistant button (e.g. Titanium). Deviations from the ASTM G32 method have to be documented.

The cavitation erosion tests presented in Chap. 5 used a sample diameter of 12.7 mm instead of 16 mm recommended by the ASTM for both the direct and alternative methods. The alternative G32 method is especially useful for testing.

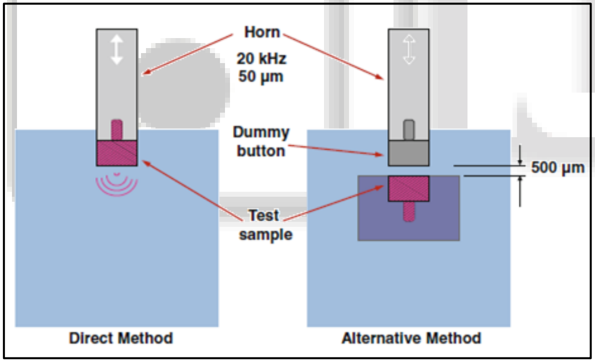


Fig. 2.2:

Sketches of the test setups for the ultrasonic cavitation ASTM G32 direct method (left) and the alternative method (right). In the direct method a hemispherical microbubble cloud is formed under the sample and collapses quasi spherically onto the sample. In the alternative method, the cloud is cylindrical and is confined between the sample and a dummy button, and collapses quasi-cylindrically.

Fig. 2.3:

Aluminum alloy Al 7075 samples tested at DYNAFLOW by ASTM G32 direct method (left) and alternative method (right). Both pictures are shown for 900 min of exposure to cavitation. (Button samples diameter: 12.7 mm)

Materials difficult to be made into threaded buttons. Sketches of both setups are shown in Fig. 2.2. Figure 2.3 shows samples with typical patterns of advanced erosion and mass loss tested by the two ultrasonic cavitation methods. The erosion patterns are significantly different, with the direct method showing a large eroded area concentrated mainly in the central part of the sample, while the alternative method shows a more spread erosion pattern. This is because the shape of the bubble cloud is different between the two schemes. In the direct G32 method the cavitation cloud collapses in a hemispherical way towards the tested sample (see Fig. 2.2 left), while in the alternative method, the cavitation bubble cloud collapses in a cylindrical way (see Fig. 2.2 right). Cavitation clouds collapsing cylindrically were found to be much less erosive than the hemi-spherically collapsing cavitation clouds [12, 19].

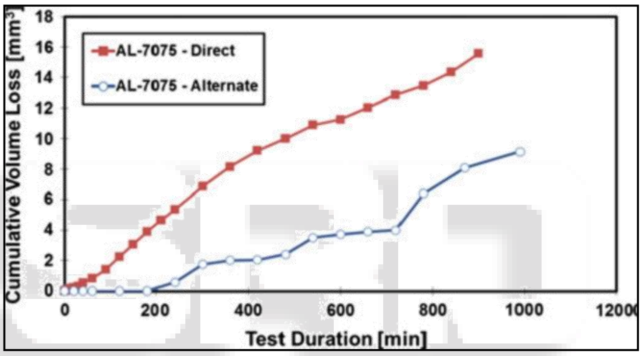


Fig. 2.4:

Comparison of material erosion progression on Al 7075 samples tested at DYNAFLOW using both the ASTM G32 direct method and the alternative method. Erosion in the alternative method progresses much slower than with the direct method

Mass loss versus time curves on the same material (aluminum alloy Al 7075) for the two methods are presented in Fig. 2.4, which illustrates a mass loss rate by the direct method being almost twice that of the alternative method.

The conventional test procedure using the ultrasonic vibrating horn method is to expose the sample to cavitation for a selected period of time, interrupt the test, remove the sample, and record weight to enable calculation of weight loss as a function of time. The sample is then returned to the exact same position on the horn for additional time intervals of erosion. Other erosion characteristics such as volume of erosion imprint, maximum width and depth can also be recorded, together with photographs of the evolution of the eroded region as a function of time.

Erosion tests using ultrasonic cavitation provide reproducible cavitation within a laboratory environment, but the cavitation thus generated is different from that on a propeller or a rudder in a number of ways. The cavitation bubbles are of nearly uniform sizes and are excited by the horn at a fixed frequency, while real cavitation fields have a distribution of bubble nuclei sizes and cavitation forms and vastly different exciting frequencies. The ultrasonic test does not include the effects of bubble nuclei captured by turbulent vortex filaments, break-up of cavities, and presence of liquid flow that interacts with the bubbles. The most important discrepancy is the presence in the ultrasonic method of a cavitation bubble cloud always at the same location.

A. Cavitating Liquid Jets (ASTM G134 and Variants)

Cavitating jets have been used extensively for materials testing because of the flexibility these jets provide to control and dial the cavitation intensity. The American Society for Testing and Materials (ASTM) established a standard method using specific conditions and orifice type under the G134 in 1995 [20].

Cavitation intensity produced by cavitating jets can be varied in a wide range through adjustment of the type of the jet, the jet velocity, the jet diameter, the jet angle, the standoff distance, and the ambient pressure in which they are discharged [14]. The jet pressure can be as high as 300 MPa for some applications. This flexibility makes a cavitating jet a useful research and testing tool to study parametrically the effect of cavitation intensity on material behavior. Compared to the ultrasonic horn testing (G32), the cavitation generated by a cavitating jet provides more realistic cavitation bubble clouds than that by ultrasonic horn, with distribution of various size micro bubbles, shear flows with vortices, and dense bubble clouds, which collapse on the sample. With the control of the operating pressure, the jet angle, and the standoff, the testing time can be controlled to provide either quick erosion for an initial screening or accelerated erosion more relevant to the real flows.

The cavitating jet erosion test setup used in the studies presented in Chaps. 3, 4 and 5 is sketched in Fig. 2.5. The test facility has two testing loops sharing one pump, i.e. only one loop is used at a time by shutting down the other loop using valves. The first flow loop that circulates water through the left side of the setup consists of a cavitating jet nozzle (CAVIJET _), a sample holder, an atmospheric test chamber, a water reservoir, and a pump. A sample holder is used to ensure that the sample can be taken out for measurements and then placed back precisely at the same location to continue testing.

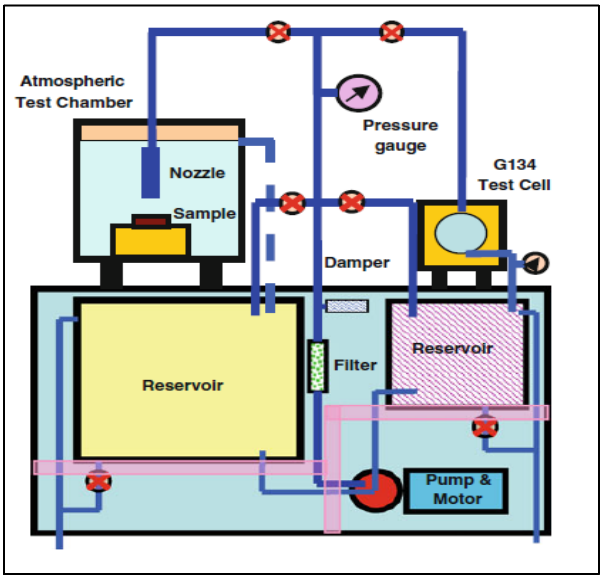


Fig. 2.5:

Sketch of the ‘‘7 ksi (48 MPa) - 5 gpm (0.3 l/s)’’ DYNAFLOW cavitating jet test loops. This loop enables selection between open atmospheric pressure tests and the G134 test, where both ambient pressure and temperature in the test section can be controlled (0.1 MPa< P_{amb}< 2 MPa, T < 300 ^{0}F)

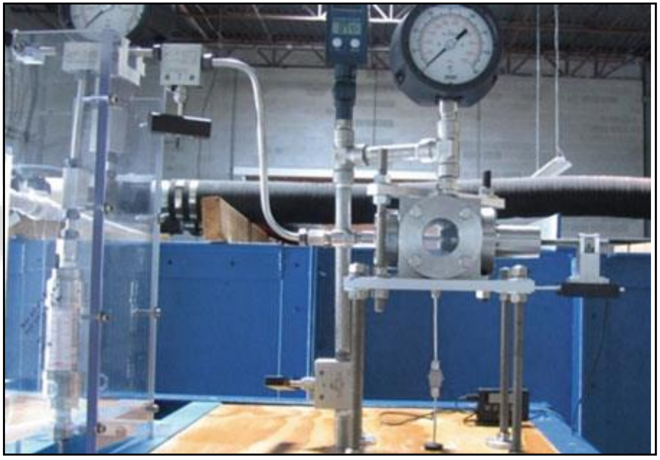


Fig. 2.6 Picture of the G134 ‘‘7 ksi (48 MPa) - 5 gpm (0.3 l/s)’’ test chamber loop

The second flow loop that circulates test liquid through the right half of the setup consists of a cavitating nozzle conforming to G134 specification (0.4 mm orifice diameter), a sample holder, a pressurized test cell, a water reservoir, and a pump. When the cavitation number needs to be controlled or maintained for different jet pressures, the jet is discharged in a pressure controlled cell, where the ambient pressure can be increased (see Fig. 2.6). This is the case for the G134 test cell setup shown in Fig. 2.5.

Different types of jets can be tested for their effect on cavitation erosion. In a conventional submerged jet (see Fig. 2.7 left), cavitation is generated in the turbulent shear layer between the high speed jet and the surrounding liquid. This results in a random distribution of elongated cavitation bubbles with some tendency to organize [21]. This tendency can be harnessed and passive acoustic enhancement can be achieved by proper design of the nozzle shape and piping assembly to result in much more erosive structured cavitating jet (see Fig. 2.7 right) [22, 23]. In this case, vorticity is collected in toroidal vortical structures, whose collapse is intense [24]. Unstructured conventional cavitating jets were used in the studies presented in Chaps. 3, 4 and 5.

For conventional materials erosion testing, where relative performance between samples is assessed, the jet and the sample are submerged in a water tank open to the atmosphere and relative erosion testing is conducted. Under these conditions, the cavitation number is very low and can be defined for cavitating jet as:

$$\sigma_{jet} = \frac{P_{tank} - P_v}{P_{jet} - P_{tank}} \ll 1,$$

Where P_{tank} is the pressure in the test tank where the sample is located and P_{jet} is the pressure upstream of the nozzle orifice.

A photograph showing a typical setup of the jet nozzle and the sample in its holder is shown in Fig. 2.8. The overall test procedure is similar to that used in the G32 tests other than using a cavitating jet. A normal test procedure for a sample is as follows: (a) the sample is exposed to the cavitating jet for a predetermined period of time, (b) the test is interrupted, (c) the sample is taken out from its holder for examination, and (d) the erosion is characterized by weight and depth measurement.

Photographs of the progression of the erosion patterns such as shown in Fig. 2.9 are taken at selected times. The sample is then returned for additional testing, and the process is repeated. The time intervals are appropriately selected to capture a cumulative weight loss curve displaying as much as possible the characteristic S-curve (see Chap. 5).

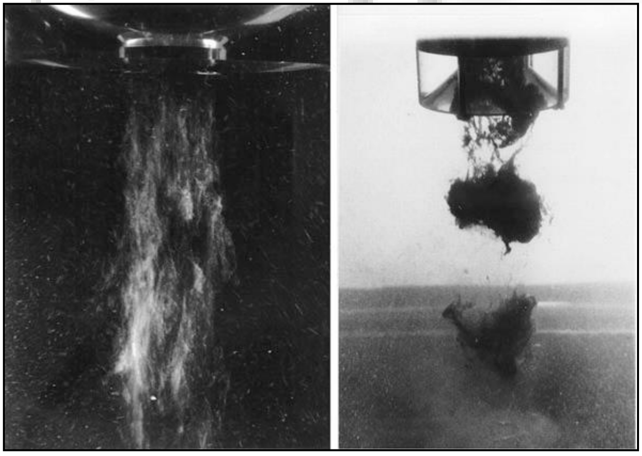


Fig. 2.7:

Conventional CAVIJET cavitating jet (left) and structured cavitating jet generated by a STRATOJET (right). Both pictures were taken using large scale nozzles geometrically scaled up while conserving cavitation number and Strouhal number. The left CAVIJET nozzle had an orifice diameter of 2.5 cm, while the right STRATOJET orifice had a diameter of 1 cm. The cavitating vortex rings in the STRATOJET were emitted with a frequency corresponding to a Strouhal number of 0.3 at the cavitation number of 0.5.

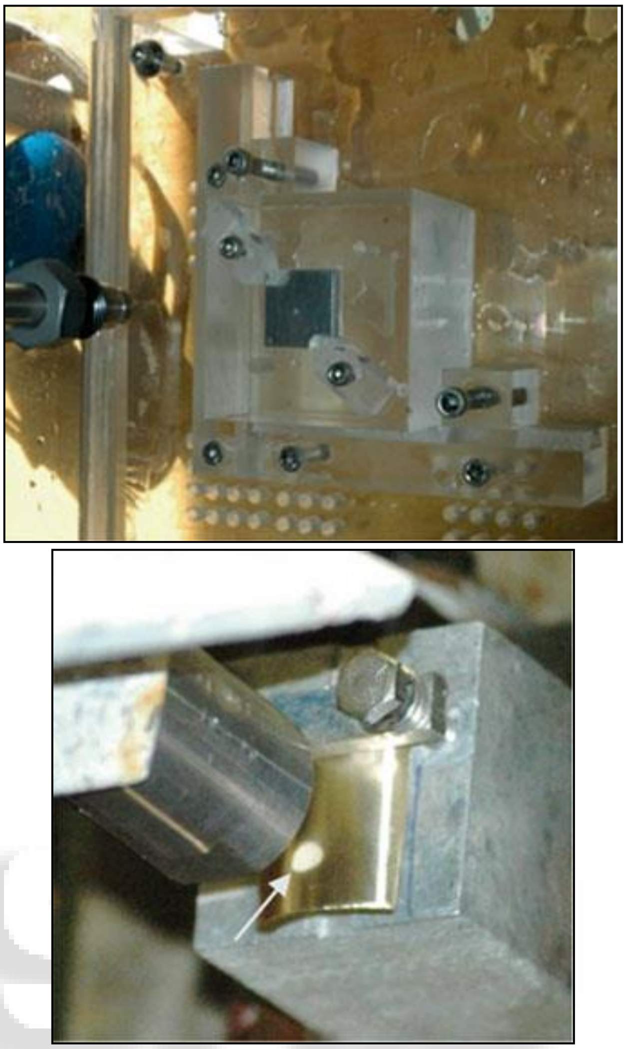


Fig. 2.8:

A typical cavitating jet erosion test setup at DYNAFLOW (left): the sample is 2.5 cm 9 2.0 cm 9 2.5 cm. The nozzle diameter is about 2 mm and the standoff distance is about 2.5 cm. The right picture shows more specialized testing; here a cylindrically shaped sample is placed under the nozzle. The whole rod piece can be held in place under the jet. The jet and the samples shown in the pictures are submerged in water during the test.

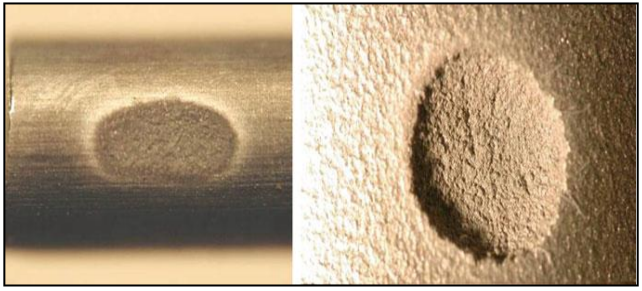


Fig. 2.9:

Cavitation erosion pattern on metals created by a CAVIJET cavitating jet. The left figure shows the erosion pattern on the rod sample shown in Fig. 2.8 (right), which explains the elliptical shape of the eroded area. The right picture shows a more typical erosion pattern on a flat sample. In both pictures the erosion areas had typical size of the order of a centimeter, the samples were surface treated proprietary stainless steels and the jet pressure was about 40 MPa.

B. High-speed Cavitation Tunnels

Cavitation erosion tests can also be conducted in high-speed cavitation tunnels. In order to be able to characterize the resistance to cavitation erosion of hard materials within reasonable exposure times, cavitating flows of sufficiently high aggressiveness are required. As aggressiveness increases with flow velocity, cavitation erosion tunnels are often designed for high velocities and consequently high pressures.

Figure 2.10 presents a typical example of such a facility. The whole facility is designed for a maximum pressure of 4 MPa (40 bar) corresponding to a maximum velocity of about 90 m/s. The facility is equipped with an 80 kW centrifugal pump, which can provide a flow rate of up to 11 l/s. A heat exchanger of 80 kW limits the increase in temperature during long duration tests. The facility comprises a downstream tank of 1 m3 pressurized with nitrogen by means of a pressurization vessel. The small section of the pressurization vessel limits the dissolution of nitrogen into water so that the dissolved gas content is expected to be almost independent of the pressurization level. Pressurization is required to control the cavitation number which, in turn, controls the extent of cavitation and the location of erosion on the sample. In addition, pressurization makes it possible to keep the cavitation number constant when the flow velocity is changed. A similar extent of cavitation is then guaranteed and the effect of flow velocity is separated from the effect of cavitation number or cavity length increase.

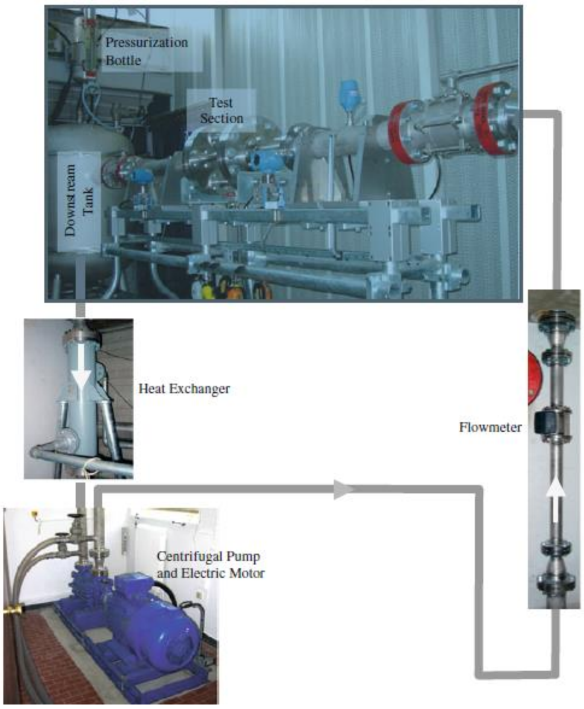


Fig. 2.10:

The high-speed cavitation tunnel of the LEGI laboratory (University of Grenoble, France) used for cavitation erosion tests. The tunnel, made of stainless steel, was designed for a maximum operating pressure of 4 MPa (40 bar) corresponding to a maximum flow velocity of 90 m/s. Adapted from [36], with permission from ASME.

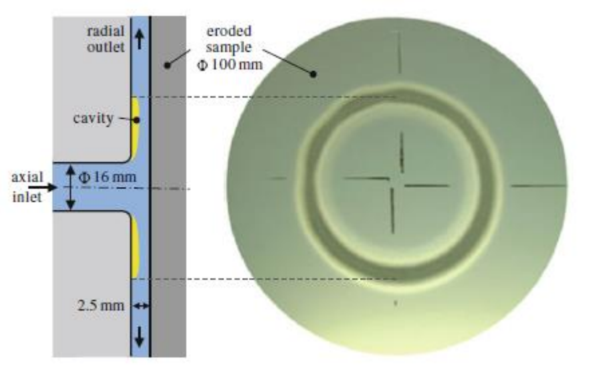


Fig. 2.11:

Schematic view of the radial divergent test section used at the LEGI laboratory (University of Grenoble, France) and typical example of an eroded sample. A cavity (in yellow) develops at the exit of the 16 mm diameter nozzle, opposite to the sample to be eroded. Erosion is concentrated in the closure region of the cavity and takes the form of a ring due to the axial symmetry of the test section. The mean diameter of the ring is of the order of 45 mm for a value of the cavitation number of 0.9 [37]. Adapted from [36], with permission from ASME.

Several pressure sensors are used to control the operating point. A flow meter measures the flow rate Q in the test section and two pressure sensors give the upstream and downstream pressures P_u and P_d respectively. They are located far upstream and downstream of the test section in the inlet and outlet ducts of large diameter (90 mm) with respect to that of the nozzle (16 mm).

The cavitation number is defined by:

$$\sigma = \frac{P_d - P_v}{P_u - P_d},$$

Where P_v is the liquid vapor pressure. A temperature sensor is also used to check that the temperature rise during long erosion tests remains limited to typically a few degrees Celsius.

Different types of test sections have been used to investigate cavitation erosion in high-speed tunnels such as a Venturi with or without a central body [25–27], slot cavitator [28–34], cylindrical specimen spanning the tunnel [35] or radial divergent [36]. As an example, the radial divergent test section used in the LEGI (‘‘Laboratoiredes Écoulements Géophysiques et Industriels’’, Grenoble, France) facility is presented in more detail in Figs. 2.11 and 2.12. The inlet flow is axial whereas the outlet flow is radial. Cavitation develops from the nozzle exit and extends into the radial diverging channel. The sample to be eroded faces the nozzle and is located at a distance of 2.5 mm. Cavitation erosion has an annular shape similar to the shape of the closure region of the cavity.

Fig. 2.12:

Visualization of the cavity in the radial divergent test section presented in Fig. 2.11. The cavity is the white region developing from the 16 mm diameter nozzle exit (small black circle in the middle). Flow is from left to right. For visualization purposes, the sample has been replaced by a perspex window, which requires operating the tunnel at a reduced velocity to avoid damage to the window. The value of the cavitation number is 0.9. Adapted from [37], with permission from ASME.

For the erosion tests conducted at LEGI, the tunnel is usually operated at a cavitation number around 0.9. With this value of r, the cavity closure point is located at a radial distance of the order of 22.5 mm from the axis (see Fig. 2.13). Using the definition (2.5) of the cavitation number, the pressure drop through the test section is:

$$P_u - P_d = \frac{P_u - P_v}{1 + \sigma}.$$

In this equation, the vapor pressure P_v is generally negligible with respect to the upstream pressure. Since the cavitation number is around 1, Eq. (2.6) shows that the downstream pressure, P_d, in the cavitating test section, and the pressure drop across the nozzle, P_u _ P_d, are each about half the upstream pressure.

Using Bernoulli equation, a typical velocity on the cavity can be derived:

$$V_c \cong \sqrt{\frac{2P_u}{\rho}},$$

Where q is the liquid density. Equation (2.7) assumes that the pressure on the cavity surface (which is expected to be close to the vapor pressure) is negligible with respect to the upstream pressure and that the velocity in the inlet duct of large diameter (90 mm) is negligible with respect to the velocity in the test section. As an example, for an upstream pressure of 4 MPa, the velocity on the cavity is V_c = 90 m/s. For this typical operating point, the measured flowrate is 8.2 l/s. The equivalent flow velocity in the minimum section area corresponding to the cylindrical section of diameter 16 mm and thickness 2.5 mm at the exit of the nozzle (see Fig. 2.11) is 65 m/s. This estimate assumes that the flow in this section is purely liquid. Figure 2.13 presents a typical example of an eroded sample profile along the radial direction. Damage is concentrated in an annular region extending roughly between radius 20 mm and radius 26 mm. The radial location of this region is controlled by the value of the cavitation number. This region moves downstream when the cavitation number is decreased and follows the increase in cavity length.

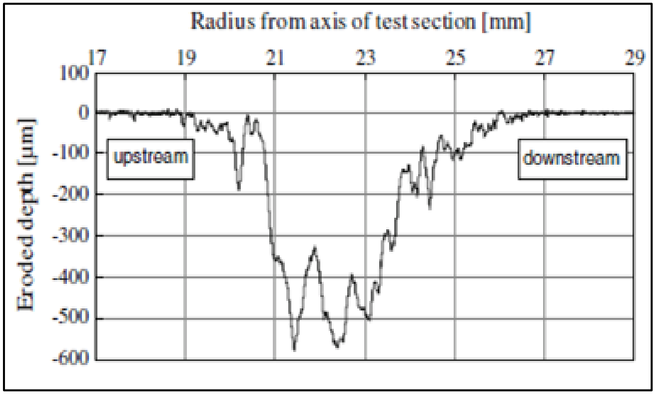


Fig. 2.13:

Typical example of a profile of a sample eroded in the cavitation tunnel of the LEGI laboratory. The horizontal axis is the radius measured from the center of the test section. The vertical axis is the depth of penetration of the damage. Level 0 corresponds to the original noneroded material surface. Erosion is concentrated in a ring of mean approximate radius 22.5 mm (stainless steel A2205, exposure time: 161 h, upstream pressure: 40 bar, downstream pressure: 18.9 bar, flow rate: 8.2 l/s)

III. NOW CHECKING THE IMPACT OF COMPONENT MATERIAL SELECTION ON PUMP RELIABILITY

Selecting the right pump type and sizing it correctly are critical components to the success of any pump application. Equally important is selecting construction materials. The initial cost of these materials is normally the first consideration. Operational costs, replacement costs and longevity of service and repair costs will, however, determine the actual cost of the pump during its lifetime.

Standard pump part materials (such as cast irons, bronzes and low-carbon steels) are typically the least expensive first cost -- and the most readily available for replacement. However, these materials can become more expensive if they cause premature failure and unexpected service and replacement.

Throughout the years, I have consulted on several wastewater lift station applications where the choice of low-cost cast iron for the pump impeller, even when coated, could not withstand the abrasives in the pumpage and/or cavitation, which were often exacerbated by low-flow suction recirculation.

Factors that must be considered in selecting materials for wetted pump parts are, for example, user's experience, expected pump life, intermittent or continuous duty, pumping of hazardous or toxic liquids, condition of the liquid, pump suction energy level, and conditions of service (especially suction conditions).

A. Corrosion

Corrosion is the destructive attack of a metal by chemical or electrochemical reaction with its environment. Corrosion by itself is usually not a difficult problem; in fact, many materials are available to handle most fluids. It is, however, important to understand the various types of corrosion and factors affecting the corrosion rate in order to select the appropriate materials. It can be quite difficult to choose a material to withstand multiple factors, such as corrosion in addition to erosion and/or cavitation. A general rule of thumb is to first select materials that will withstand corrosion and then select the one with the most appropriate abrasion and/or cavitation resistance. Further, the corrosive properties of the liquid may vary with one or more of the following liquid conditions: temperature, concentration, purity, velocity, suction pressure, entrained air, and entrained solids.

B. Abrasive wear

Abrasive wear is the mechanical removal of metal from the cutting or abrading action of solids carried in suspension in the pumped liquid. The rate of wear for any material is dependent upon the following characteristics of the suspended solids:

1) Solid concentration
2) Solids size and mass
3) Solids shape (spherical, angular or sharp fractured surfaces)
4) Solids hardness
5) Relative velocity between solids and metal surface

The rate of wear is also dependent upon the materials selected for the rotation and stationary components of a centrifugal pump. Although metal hardness is not the sole criterion of resistance to abrasive wear, hardness does provide a convenient index in selecting ductile materials usually available for centrifugal pumps. Such an index is shown in Figure 1, where the abrasive wear resistance ratio is shown as a function of Brinell hardness for various materials. It should be noted that a brittle material, such as cast iron, exhibits a much lower ratio than either the steels or bronzes of the same hardness. The following tabulation can also be used as a guide in material selection, listed in order of increasing abrasive-wear resistance:

1) Cast iron
2) Bronze
3) Manganese bronze
4) Nickel-aluminum bronze
5) Cast steel
6) 300-series stainless steel
7) 400-series stainless steel

C. Abrasion-Corrosion

The corrosion rate of most metals and alloys in any liquid environment under static conditions depends upon the resistance of the film that forms on the surface and protects the base metal from further attack. Damage to or removal of this film by abrasion exposes the unprotected base metal to the corrosive environment, and metal removal continues unabated.

When the liquid pumped is corrosive and also contains abrasive solids, higher alloyed materials (such as stainless steel) are often required to achieve acceptable pump life. The use of such alloys is more important when a pump is operated only intermittently and not flushed after each pumping cycle.

In centrifugal pumps, the impeller is particularly susceptible to abrasion-corrosion. Although the casing can be damaged by this, the problem is usually secondary to that of the impeller. The diffuser-type casing with its many vanes is more susceptible to abrasion-corrosion than is the volute-type casing with only one vane -- the casing tongue -- as an obstruction to the line of flow.

Wearing rings are also susceptible to abrasion-corrosion and should receive special consideration in material selection. The higher fluid velocities through the small clearance annulus can result in a high rate of wear, unless the proper material is selected. Cavitation-Abrasion-Corrosion Cavitation erosion (which can normally occur with high-suction energy pumps) is the removal of metal as a result of high, localized stresses produced in the metal surface from the collapse (implosion) of cavitation vapor bubbles in higher pressure regions of the impeller inlet. In an abrasive-cavitation and corrosive environment, the rate of damage is further accelerated and can occur even in low-suction energy pumps. The base material is eroded away as the abrasive particles are accelerated towards the impeller surface (by the implosive force of the cavitation bubbles), which continuously removes the corrosion products so metal removal proceeds unabated.

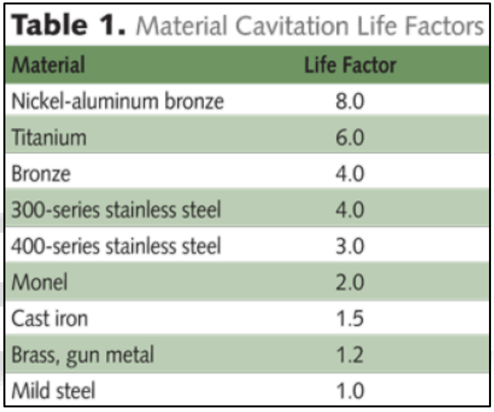
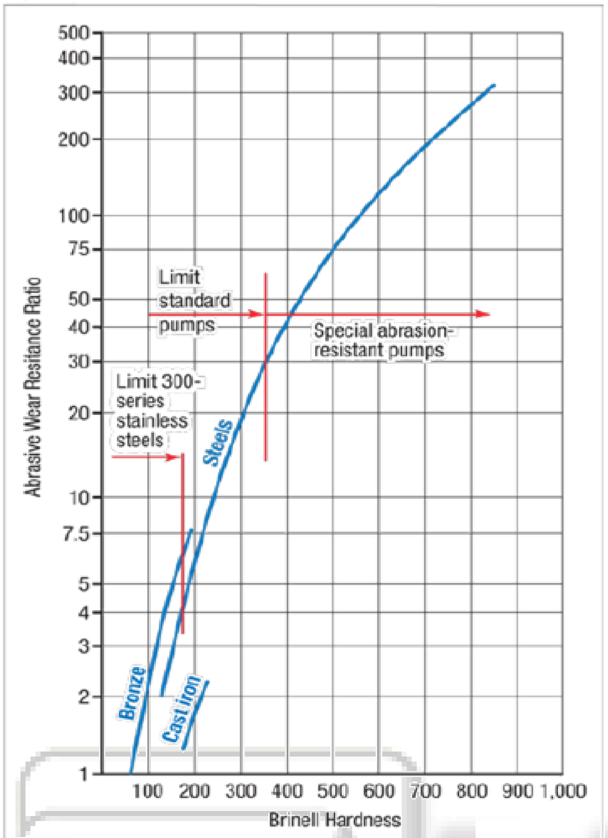


Table 1. Material Cavitation Life Factors

Material	Life Factor
Nickel-aluminum bronze	8.0
Titanium	6.0
Bronze	4.0
300-series stainless steel	4.0
400-series stainless steel	3.0
Monel	2.0
Cast iron	1.5
Brass, gun metal	1.2
Mild steel	1.0

While every effort should be made in the design and application of centrifugal pumps to prevent or minimize cavitation, especially with high-suction energy pumps, it is not always possible to do so. It should be noted that the published net positive suction head requirement (NPSHR) curve is not sufficient to suppress all cavitation damage. It can take four times this NPSHR value, on average, to fully eliminate all cavitation in a pump. In previous columns, I've discussed recommended NPSH margin ratios. If the desired margins cannot be provided, an impeller material with good cavitation resistance should then be selected. The impact of the impeller material on the life of a high-suction energy pump under cavitation conditions is shown in Table 1. As an example, changing from mild steel (reliability factor of 1.0) to stainless steel (reliability factor of 4.0) would increase the impeller life from cavitation damage by a factor of four. Hard coatings, such as certain ceramics, can also increase the impeller life under cavitating conditions.

Figure 1: Abrasive Wear Resistance Ratio versus Brinell Hardness



Source: Image courtesy of Karassik et al., "Pump Handbook."

IV. CONCLUSION

In summary, the following criteria should be considered in the selection of the material for a centrifugal pump impeller and/or casing:

1) Corrosion resistance
2) Abrasive-wear resistance
3) Cavitation resistance
4) Strength (primarily for the casings)
5) Casting and machining properties
6) Cost

For most water and other noncorrosive services, bronze satisfies these criteria for the impeller and thus is the most widely used impeller material for these services. Cast iron impellers should generally be used to a limited extent in small, low-cost pumps. As cast iron is inferior to bronze in corrosion, erosion and cavitation resistance, low initial cost would be the only justification for a cast iron impeller. Further, stainless steel impellers are widely used where bronze would not satisfy the requirements for corrosion, erosion and/or cavitation resistance. For the pump casing, cast iron is the generally preferred material in most water and wastewater pumping applications.

A detailed description of cavitation erosion facilities and equipments was given together with typical measurement results. The facilities include an ultrasonic vibratory horn (G32), a cavitating jet (G134 and its variants) and a high-speed cavitation tunnel with a radial divergent section. They were systematically used to investigate cavitation erosion and the test results are presented in Part I of this book. They include:

- Relatively short duration tests to investigate the cavitation incubation period, various materials pitting, and to deduce impulsive loads on the material (Chap. 3).
- Measurements of the cavitation pressure loads on transducers in order to characterize the amplitude and frequency distribution of cavitation impulsive pressures (Chap. 4).
- Long duration tests to characterize mass loss evolution with time due to cavitation erosion on various materials for different cavitation aggressiveness levels (Chap. 5).

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