72-02

BRITISH ACOUSTICAL SOCIETY: Meeting on "Macrosonics" at Chelsea College of Science and Technology on the 23rd March, 1972.

ULTRASONIC AIDS TO CAVITATION EROSION RESEARCH

by

J M HOBBS

---

1 INTRODUCTION

The formation of cavities in liquids by ultrasound and the production of damage when they collapse are now well known phenomena. However, while cavitation erosion research has been undertaken continually since the beginning of the century and use has been made of vibration to generate cavitation during the last forty years, only within the last fifteen years or so have truly ultrasonic devices been employed. In the main these were the result of a natural development of the early type of vibrators.

It is generally accepted that the first record of a magnetostrictive transducer being used for cavitation studies was in 1932 when the work of Newton Gaines was published[1]. His nickel tube transducer resonated by 8.9 kHz with an amplitude of 30 μm (peak-to-peak) producing cavitation pitting of metal samples attached to the tube and immersed in water. The great potential of this device was quickly realised and several workers in the United States made improved versions of the basic equipment during the 1930s. A diagram of the usual arrangement is shown in Fig. 1.

In Britain, the first concentrated efforts at using a magnetostrictive transducer to discover cavitation erosion resistant materials were reported in 1942 by Beeching[2]. About the same time similar work was being carried out in Europe. All these early workers must have suffered repeated setbacks owing to the fatigue of their transducers and the sometimes inadequate amplitude monitoring equipment. It is therefore very commendable that they managed to classify materials in an order which has remained almost unchallenged to this day.

Better engineered transducers did not appear in cavitation research until the late 1950s. The work of Pisarevskii and Erashov[3] in Russia and of Plesset[4] in the USA are probably the first reported using modern transducers comprising a stack of nickel laminations carrying a velocity transformer. Both used frequencies appreciably higher than was necessary with nickel tubes and the former operating at 20 kHz was probably the first to be truly ultrasonic.

In Britain shortly afterwards, commercially available 20 kHz ultrasonic drilling equipment was adapted for cavitation erosion testing[5]. New devices employing both magnetostrictive and piezoelectric transducers were also set up in the USA. From these installations it soon became apparent that the modern transducers were more efficient and reliable and offered greater ease of operation and control than the nickel tube devices. Hence their use has spread and the specification of standard conditions for cavitation erosion testing is being considered by the ASTM.

2 RECENT DEVELOPMENTS OF THE VIBRATORY TEST

The most common arrangement of the vibratory test, the open beaker test, is shown in Fig. 2. Disc testpieces screwed into the probe dip into the beaker of test liquid which stands in a water bath. While this was found to be satisfactory for the evaluation of most metals, it had two main disadvantages. The first was, because of the high acceleration experienced by the testpiece, weak or brittle materials tended to break during a test making it impossible to evaluate them. Coatings also tended to flake off prematurely before damage rates could be assessed. The second disadvantage concerns the irregular and unrepeatable damage patterns observed when tests were made in mineral oils and other viscous liquids. In these tests not only were the erosion patterns random but, in addition, the actual condition of the fluid in the cavitation zone was not accurately known.

The problem of failing testpieces was first tackled about 1956 by Schrader[6], who, using a nickel tube transducer, showed that cavitation energy could be transmitted across a film of the immersing fluid to damage a stationary testpiece. It is surprising to note that apparently this idea was not followed up until recently. This may have been because the damage rate was relatively low and while eliminating the vibrating testpiece, it aggravated the problem of knowing the fluid condition.

A very neat solution to both problems of overstressed testpieces and of the test liquid condition was proposed by Rachman[7] who used the anvil arrangement shown in Fig. 3. By feeding fresh liquid into the film through a small hole in the centre of the stationary testpiece it is possible to control the condition of the test liquid without suppressing the cavitation. The flowing liquid also served to displace eroded particles and any air bubbles which have grown in the film beyond a collapsible size. Thus the anvil test retains all the essential features of a vibratory test while disposing of the problems of changing atmospheric pressure, inertia stressing, and unpredictable variations in temperature and gas content.

3 EVALUATION OF MATERIALS EROSION RESISTANCE

Most metallic engineering materials can be assessed quite simply using the open beaker form of test. Erosion behaviour is revealed by reference to the variation of weight loss with time, a typical example being shown in Fig. 4. The shape of the erosion rate/time curve has been found to depend mainly upon the actual conditions of the test, in particular, the frequency and amplitude. The various zones obtained under normal test conditions for a wide variety of metals correspond to distinct stages of the erosion process. In conducting comparative tests it is important that the erosion behaviour of different materials should be assessed over the same stage of the process. The author believes that the best stage is in phase 3 where the steady rate of erosion occurs. Using this method at NEL over 70 different materials, including stainless steels, bronzes, nickel alloys, aluminium alloys, and titanium alloys have been evaluated. The results of these tests have been published in full as NEL Reports[8,9].

As stated in section 2, weak metals cannot be tested in the open beaker, but are easily evaluated in the form of stationary testpieces. The test conditions and procedure are similar to those used in the open beaker with the addition of a controlled flow of water through the prescribed gap. Similar erosion/time curves are produced and the erosion rates are just under half those obtained in the open beaker (Table 1).

With the 'anvil' method many non-metallic structural materials and coatings become amenable to evaluation. Recent tests have been made on glass fibre and carbon fibre composites and ceramic coatings with complete success. Difficult materials are those whose acoustic properties result in local heating, softening, and possibly self destruction.

4 EFFECT OF FLUID PROPERTIES ON CAVITATION DAMAGE

As only a small volume of test liquid is required, the vibratory cavitation erosion test is ideal for relating erosion behaviour to fluid properties. However, both the area and intensity of the cavitation cloud can be affected by fluid properties, giving misleading results. The method employed must therefore be chosen according to the behaviour observed. For example in the open beaker test, many low viscosity fluids such as acetone, produce cavitation clouds and damage patterns that are indistinguishable from those obtained in water. Thus, much can be learned about the process if the erosion rates of standard testpieces are correlated with the physical properties of such liquids. This has, in fact, been done at NEL for organic liquids chosen to give a wide range of vapour pressure. Other properties (density, viscosity, surface tension) were kept sensibly constant, but the erosion rates proved to be relatively insensitive to vapour pressure and correlated best with small, though significant, differences in sound velocity.

Open beaker tests on more viscous liquids such as mineral oils and hydraulic fluids were misleading for the reason stated earlier. These were therefore evaluated using the anvil arrangement. Unlike the anvil tests with water, in which the rate of erosion was sensibly constant, with these fluids the erosion rate varied with time and hence the analysis of the results proved more difficult. Typical results of tests in hydraulic oils and fire-resistant fluids are shown in Fig. 5.

5 CONCLUSIONS

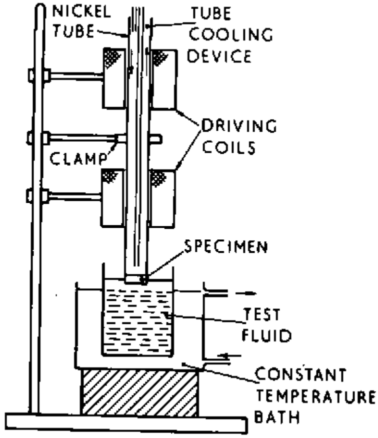
The growing application of ultrasonic devices to cavitation erosion research has been reviewed. They offer a quick and cheap method of sorting materials on a comparative basis. If the basic apparatus is modified, fluid effects can be examined, although the interpretation of the results becomes more difficult.

REFERENCES

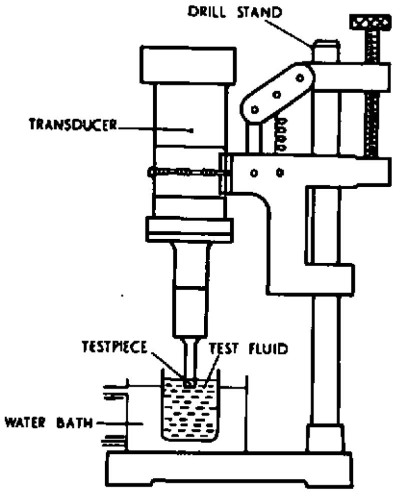
1 GAINES, N. Physics, 1932, 3(5), 209-29.
2 BEECHING, R. Trans. Instn Engrs Shipbld. Scotland, 1942, 85(5,6) 210-76.
3 PISAREVSKII, M M and ERASHOV, E F. Energomashinostroenie, 1957, (9), 38-39.
4 PLESSET, M S. Trans ASME J Basic Engng, 1960, 82(4), 808-20.
5 HOBBS, J M. NEL Report No 149. National Engineering Laboratory, 1964.
6 SCHRADER, A R. Paper No 759. New York: Society of Automative Engineers, 1957.
7 RACHMAN, D. Proc. Instn Mech Engrs, 1967-68, 182(3G), 102-104.
8 HOBBS, J M and LAIRD, A. NEL Report No 495. Glasgow: National Engineering Laboratory, 1971.
9 LAIRD, A and HOBBS, J M. NEL Report No 496. National Engineering Laboratory, 1971.

TABLE 1 – *Anvil Tests in Water*

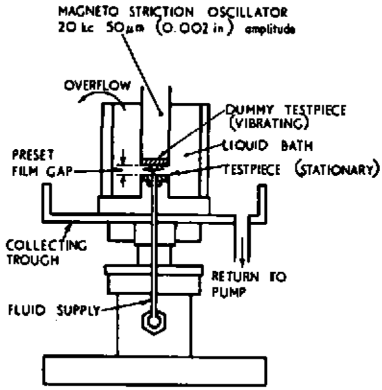
Material	Erosion rates		
	Anvil	Open beaker	Relative
	mg/h	mg/h	per cent
Tellurium copper	98	247	40
Aluminium	26.5	76	35
Nickel	13.1	35.4	37
Stainless steel	6.7	17.6	38
Aluminium bronze	2.47	6.3	39



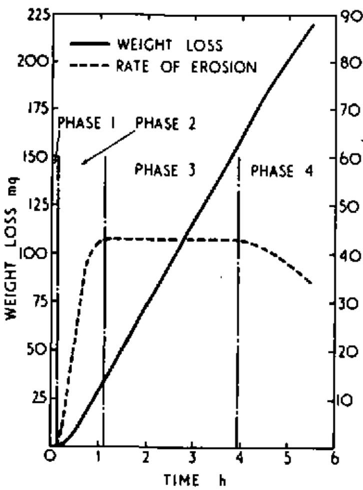
1 Early vibratory apparatus



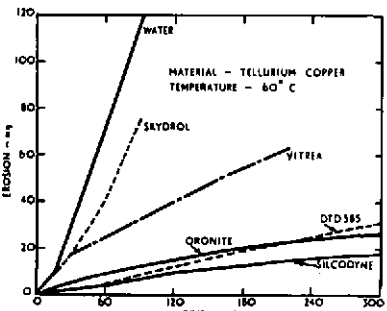
2 Modern open beaker equipment



3 Anvil apparatus



4 Total erosion and rate of erosion against time



5 Erosion by hydraulic oils and fire resistant fluids