RECENT ADVANCES IN CAVITATION DAMAGE THEORIES

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Present space power systems must in many instances operate using fluids flowing in a cavitating regime to attain required weight, space, and performance limitations. Since in many cases long, unattended life is also requisite, it is necessary to attain the capability of estimating probable cavitation damage effects under long-term exposures and also of selecting the optimum materials to be used in critical locations. Such locations include many fluid-flow components as pumps, valves, nozzles, orifices, etc., and also journal or thrust bearings*, gear teeth*, etc.

While the state of the art of cavitation damage research does not at present allow the attainment of the above objectives, considerable progress has been made in this regard in recent years, and there is hope that continuing efforts will, in the relatively near future, attain a substantial clarification of the phenomena involved, so that at least engineering damage estimates and optimum material selections will become possible. It is the purpose of the present paper to review the present state of the art with regard to the relations between material, fluid, and flow properties and parameters, and cavitation damage.

The present difficulties in obtaining a clear-cut correlation between the various independent parameters of the problem and the resultant cavitation damage lie principally in the following factors:

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* Hunt, J. B., "Cavitation in Thin Films of Lubricant", <u>The Engineer</u>, Jan. 29, 1965, pp. 22-23.

i) Uncertainty regarding mode of cavitation bubble collapse and resultant damaging mechanism - spherical, toroidal, etc.

ii) Uncertainty regarding actual mode of material failure. An unknown and varying (depending upon flow, fluid, and material parameters) combination of the following is probably involved:

a) Single-blow cratering (similar to craters produced by liquid or solid impingement).

b) Fatigue failure caused by many weaker blows.

c) Fatigue failure caused by stronger blows causing substantial plastic deformation, although not actual craters.

d) Chemical effects as corrosion, stress-corrosion, etc.

The mechanical material and/or fluid properties expected to be involved obviously depend upon the mode of material failure.

iii) Interplay between fluid and material properties which depends on mode of bubble collapse and mode of material failure. Different fluid properties become important for different modes of bubble collapse. Possible fluid and/or fluid-material coupling parameters of interest include:

a) Acoustic impedence ratio

b) Fluid density

c) Bulk modulus of fluid, or equation of state of fluid relating pressure and density changes

d) Viscosity and surface tension

e) Gas content of fluid (which can conceivably either increase or decrease damage in a given situation through its conflicting influences on bubble nucleation and collapse). Large quantities of entrained gas are known to inhibit damage.

iv) Since the situation is so complex from the fluid, material, and flow aspects, the results from a given cavitation test (as vibratory) may not apply to a given flowing situation. The same correlations do not apparently hold for different types of facilities. Hence eventual checks of materials in a flowing situation approaching the prototype situation as closely as possible are highly desirable.

A consideration of the limiting conditions of a very hard non-ductile material, and of a relatively soft but highly-ductile material, both of which are often relatively immune from cavitation damage, indicates that a correlation between material properties and damage should include terms proportional to endurance limit (as, e.g., yield strength, etc) and also terms proportional to a combination of strength and ductility as strain energy to failure, impact strength, hardness, etc.

Obtaining of suitable material mechanical properties is uncertain because of:

i) Lack of reproducibility between supposedly similar materials due to different cold-work, heat-treat, etc.

ii) Possible effects of high rate of loading in cavitation as opposed to semi-static loading in the standard tests. Impact strength is of course an exception.

iii) Considerable detail required for some applicable properties as strain energy to failure where the degree to which ductility in the failed section is considered becomes of substantial importance. The calculation of this parameter requires information not usually available for most materials.

Typical curve-fitting correlations from the University of Michigan tests, for both a vibratory facility and a flowing (venturi) facility are presented. The fluids tested are Pb-Bi, Hg, and water. Test temperatures ranged from 1500°F to 70°F. In general, the resultant least mean square fits involve combinations of both strength and energy properties, as is expected according to arguments stemming from consideration of the modes of failure and limiting conditions of both very hard-brittle, and also soft-ductile materials.