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学 位 論 文 題 目	Experimental Studies on the Mechanism of Vibratory Cavitation Erosion （振動子キャビテーション壊食の機構に関する実験的研究）
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論　文　内　容　要　旨

The purpose of this study is to explore the severe cavitation erosion mechanism for a typical erosion-resistant material, SUS 304 stainless steel, under a specified condition of uniform nuclei distributions. The ASTM-Standard vibratory-method is used to generate the cavitation erosion. By using the scanning electron microscope, the profilometer and X-ray microanalyser, the erosion patterns, the surface-roughness-aspects and the particles produced by cavitation erosion are systematically observed. As well as, the cavitation aspects for the eroded surface are photographed using a xenon-flash lamp of 1 μs exposure time.

The ultrasonic cavitation, by which the erosion is extremely accelerated, is multitudinously constituted by the highly erosive massive bubbles, the erosive torus bubbles with microjets and the low erosive cloud. According to the detailed inspection of the material failure features and the cavitation aspects, it is clear that the important mechanism to transfer the cavitation energy to the solid is only explained by shock pressures accompanied by collapsing massive bubbles (see Fig. 1 for the illustration).

When the ductile materials such as SUS 304 exposed to cavitation erosion, their exposed surface are locally plastically deformed resulted in the undulation of the surface. In addition the pits are formed. As the time elapses, the plastic deformation lines are developed in the height and width but not in the shape. Once the work-hardening capacity of the surface reaches a critical case, then the cracks are initiated at the favorite sites of stress concentration like the discontinuity of slip bands, polishing lines, pits and microvoids (see for example Fig. 2). It is observed that the crack initiation and firstly propagation are inclined to the test surface (see Fig. 3). It is also observed several developed fractures have resulted in fatigue striations (see Fig. 4). These features of the eroded surface are very similar to that of the plastic fatigue process. In the vibratory erosion tests, the shock pressure pulses lower than the material strength which are resulted from the massive bubble collapses, cause the plastic deformations of the material on the local scale. The successive development of these deformations under the repeated impacts of the shock pressure pulses lead to the plastic fatigue failure.

It is found that the change in the surface roughness with time can characterize the change in the erosion patterns especially in the initial stages. Therefore the surface roughness measurements can be used as a practical and a reliable method to assess the cavitation erosion especially for the ductile materials which are widely used for manufacturing the hydraulic machinery blades (see Fig. 5).

The initial surface roughness has deleterious effects on the progress and the development of the cavitation erosion even if the roughness is one figure smaller than the value recommended by the ASTM Standard. It is observed that the roughness acts as favorite sites for the stress concentrations which give rise to many pits to form along the polishing lines and to the crack initiations and propagations. As well as, the roughness gives rise to many linear particles to fall off. The ASTM Standard on the initial roughness is said to be insufficient.

An attempt is made to observe the pits plastically formed and their effects on the development of the erosion. It is found that the diameters and shapes of the pits do not change with the test time as if they are resulted from single cavitation jet impacts of torus bubbles collapsing close to the surface. The rate of pit formation with time is high initially, but rapidly decreases with time. Clearly, some pits have some role on the initiation of microcracks.

Further clarification to the cavitation erosion mechanism is made through the observation of the particles produced by cavitation erosion. Most of the observed particles show the traces of the plastic deformations and a layered structure (see Fig. 6), which enhance the possibility of their removing by the plastic fatigue process.

The cavitation nuclei, which are the most powerful factor in controlling the cavitation types, are monitored before and after the tests. It is found that the nuclei-distributions scarcely change before and after every test run when clean tap water is settled for 24 hours at least. Under these conditions of uniform nuclei-size distributions, all the test runs of the present work are carried out.

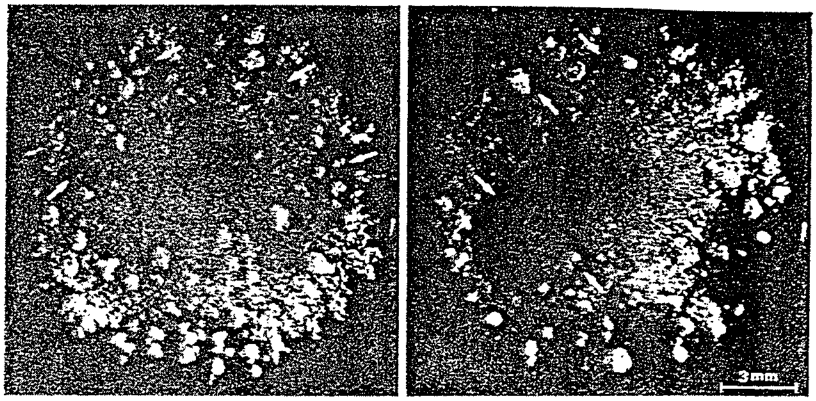

Fig. 1 Cavitation aspects of the surface eroded for 4 min showing the shock wave emitted from the massive bubble collapse

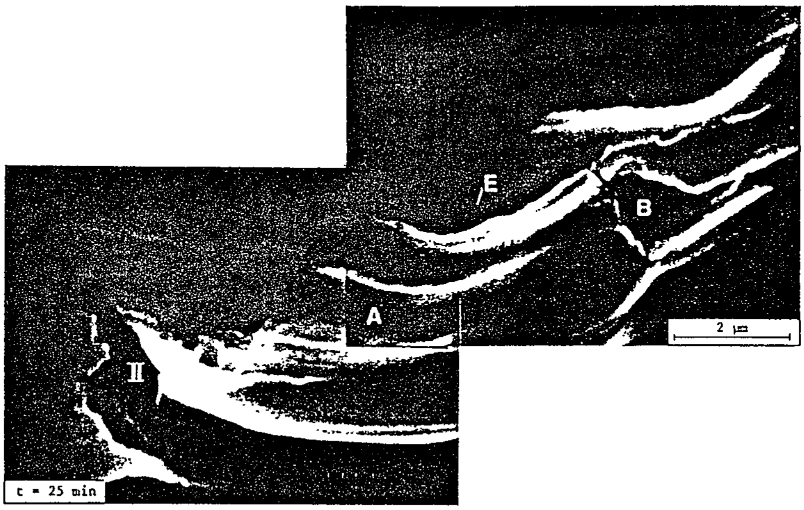

Fig. 2 Starting stages of the fatigue crack initiated from the pit formed on the surface of slip bands

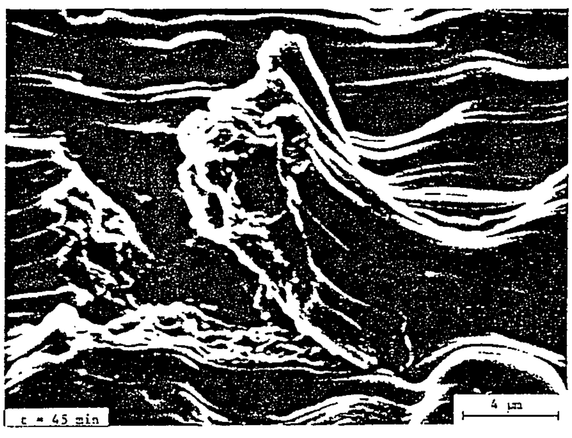

Fig. 3 Initiation and progress of the fatigue crack

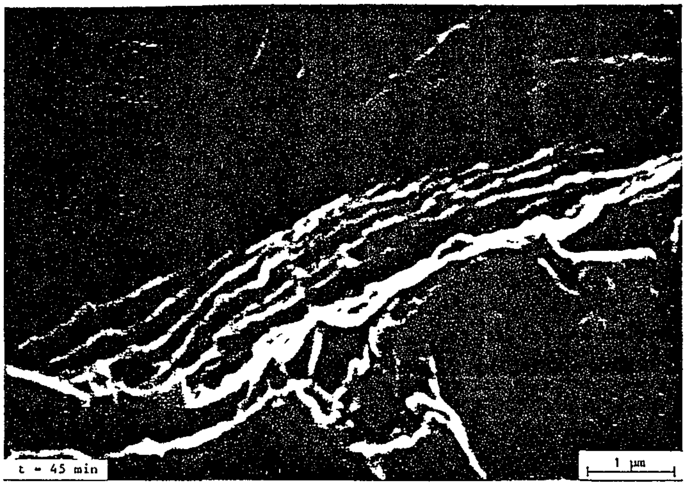

Fig. 4 Fracture surface showing a fatigue striations

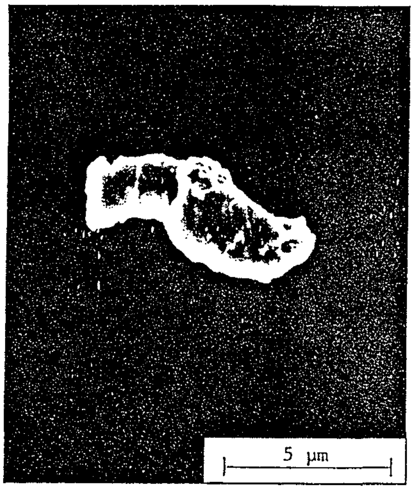

Fig. 6 Micrograph of longitudinal shaped particle

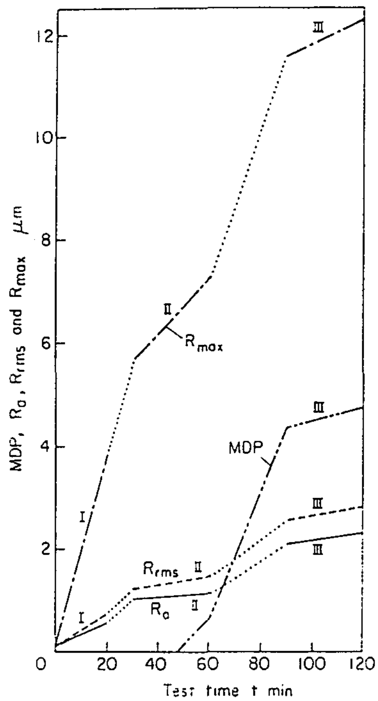

Fig. 5 Change of mass loss MDP, average roughness, RMS roughness R_{rms}, and maximum roughness R_{max} with t

審 査 結 果 の 要 旨

流体機械の高速化とともに，壊食率が従来より1～2桁も大きく，機械寿命の短縮に直結する「激しい壊食」の防止法の確立が緊要とされている。本論文は，ここで取り上げた振動キャビテーションが極めて激しい壊食性を示す事実と，キャビテーションは壊食性が全く異なる種々のタイプのキャビテーションより多元的に構成されているとの周知の事実を踏まえて，激しい壊食の機構の解明を試みたもので，全編10章からなる。

第1章は緒論である。

第2章では，ASTM 規格振動試験法において，キャビテーションの支配因子であるキャビテーション核の経時変化を詳細に調べ，核の経時変化の僅少性の見地からは，ASTM 規格は明らかに不十分で，少くとも待ち時間60分が必要である事実を示した。

第3章では，やはり規格壊食試験において，代表的耐食材であるSUS304ステンレス鋼の壊食の経時変化の様相を走査電子顕微鏡（SEM）およびあらさ計により詳細に観測し，あらさにより壊食の発達段階の判定が十分可能であることを示した。

第4章では，SUS304の潜伏期初期の壊食面のSEM観察により，激しい壊食は主として塑性変形に起因する表面波紋から発達し，壊食ピットは二次的役割しか演じないという重要な事実を明らかにした。

第5章では，振動キャビテーションの様相を超高速立体写真観察し，激しい壊食をおこすキャビテーションの一種に「強い衝撃波を伴う塊状泡」があることを明らかにした。

第6章では，ASTM 規格の試験片表面あらさは明らかにあら過ぎること，さらに，規格の1／10の微小あらさの試験片でもかなりの影響が現れる事実を，SEM 写真による観測から明らかにした。

第7章および9章では，壊食面および壊食粒子のSEM 観察により，支配的壊食の機構，疲労破壊の特徴的挙動，すなわち，ストライエーション，タイヤトラック，すべり帯，研摩痕やピットの効果などを明らかにした。

第8章では，SEMとX線マイクロアナライザによる壊食粒子と壊食面の観察により，深さ方向への壊食の進行過程を解明するとともに，粒子の観察より壊食の発達段階の推定が可能であることを示した。

第10章は結論である。

以上要するに本論文は，激しいキャビテーション機構について幾つかの重要な知見を加えたもので，流体工学ならびに流体機械学の発展に寄与するところが少なくない。

よって，本論文は工学博士の学位論文として合格と認める。