3 EXPERIMENTAL DATA

3.1 GENERAL SURVEY

Although all the Test Participants have made a significant effort to follow the recommendations given in the early ICET messages, a considerable differentiation in the scope of data submitted can be noticed.

Most of the rigs were used to test all the metallic materials. However, some tests had to be abandoned. In few cases the Test Co-ordinator was not able to submit material samples of sufficient size. This was the reason why the cavitation tunnel at the Tsinghua University (Beijing, China) had to be completely excluded from the ICET programme. Another tunnel (CSSRC lab, Wuxi, China) appeared not suited for testing highly resistant materials, like carbon steel 45 or chromium-nickel steel 1H18N9T.

Severe difficulties occurred at numerous facilities when testing the polyamide 6 (tarnamide) plastics. Tests had to be abandoned at some vibratory rigs, including those designed according to the ASTM G-32 standard, as in view of extremely low density of the tarnamide plastics, there was no possibility to keep the horn/sample system in resonance at the prescribed frequency. Due to water absorbing properties of the tarnamide plastics no mass loss was observed during tests at low cavitation rates. In some cases the effect was completely opposite to the expected one - evident mass increase of the specimen was stated. Special precautions consisting in keeping the specimen in water prior to the test and using a reference specimen[1] did not always appear sufficient. The scale of difficulties can be illustrated by the experience of the University of Hiroshima lab where lack of any volume loss was stated after 58 hours of testing at the vibratory rig and some 365 hours of cavitation exposure in the cavitation tunnel. In fact, it was only in the IMP PAN, at the Tsinghua University and at the University of Cape Town where vibratory tests allowed to draw the cumulative mass/volume loss curves for the tarnamide plastics. In case of cavitation tunnels the situation was even more difficult as the only lab having determined such a curve was that of the Pumped Storage Power Plant Hohenwarte II (VK-AG Peitz). The tests at rotating disks and the liquid impact device appeared much more successful. One can suppose that powerful periodical shocks at the liquid impact device resulted in stress and strain propagation in whole the bulk of material leading thus to a pretty high erosion rate.

The scatter in test duration (from 30 minutes for aluminium at the liquid impact rig in Olomouc up to 365 hours for tarnamide in the cavitation tunnel in Hiroshima) can be attributed to a very wide spread of erosion rates. In spite of significant flexibility shown when selecting test duration, in numerous cases the steady-state period was not attained - sometimes due to the test having been stopped during the damage rate decrease, but quite often due to the deceleration period being immediately followed by a further rise of erosion rate.

Differences in cavitation intensities are manifested by an extremely wide range of absolute volume losses and mean depth of erosion after a comparable exposure period (e.g. 1.67 mm^3 volume loss and 2.8 μm erosion depth in an aluminium specimen after a 1400 min test in the CSSRC cavitation tunnel and 1.32 cm^3 volume loss and 2 mm erosion depth after a 1200 min test of the same material at a rotating disk in the IMP PAN lab).

[1] Following this procedure, during a cavitation erosion test of a water absorbing specimen, a reference sample is kept in water. The net change of mass is calculated by subtracting the mass of eroded specimen from that of the reference one. Additionally, both specimens are kept in water for some time before starting the test.

Fig.8 Aluminium specimen after a 120 min test at the vibratory rig of the University of Hiroshima (specimen size: ∅ 16 mm).

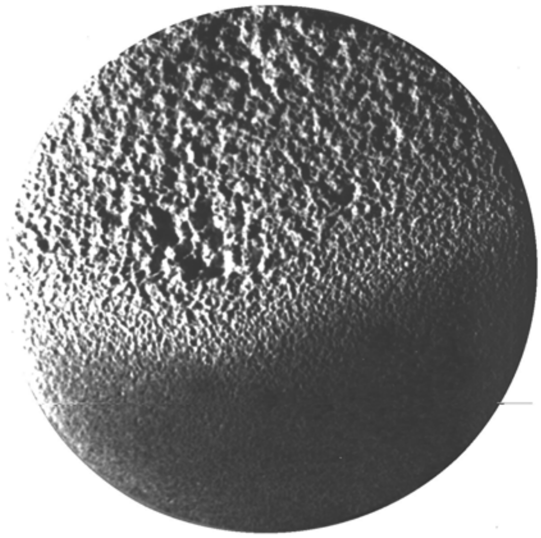

Fig.9 Aluminium specimen after a 1200 min test at the cavitation tunnel of the University of Hiroshima (specimen size: ∅ 36 mm)

Most of labs have supplemented their volume loss tables with the final erosion area, maximum depth of erosion and microhardness distribution data as well as photographs of eroded specimens which have appeared to be of great help in case of any doubts. Typical examples of aluminium specimens tested at a vibratory rig and a cavitation tunnel can be seen in Figs 8,9. Three labs (Universities of Cape Town, Hull, and the Tsinghua University of Beijing) have furnished their vibratory test documentation with photographs allowing for a detailed study of eroded surface and the metallographic structure of materials tested (Figs 10, 11). Statistical study of roughness profile was submitted by Professor Jitang Huang of the Tsinghua University. In some cases the additional data comprise also photographs of a specimen taken during the erosion progress (FCRI, CSSRC) and detailed data on the maximum erosion depth vs time progress (FCRI, VK-AG Peitz, Hiroshima University). In case of no volumetric losses observed at tarnamide specimens, the maximum depth of penetration curve could be used to infer on the erosion progress.

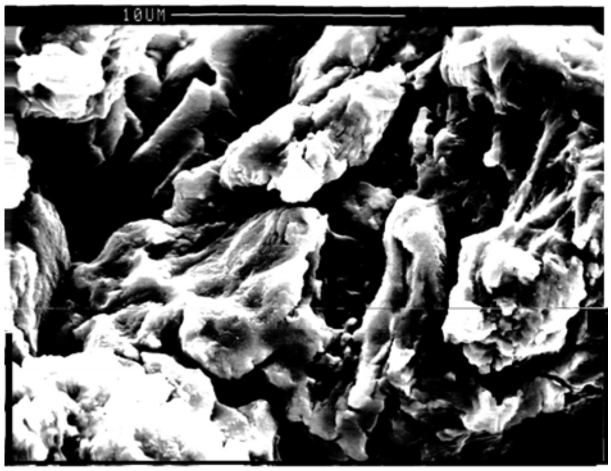

Fig.10 Scanning electron microscopy of the cavitated surface of an M63 brass specimen after a 6 hours test at the magnetostrictive rig of the University of Cape Town

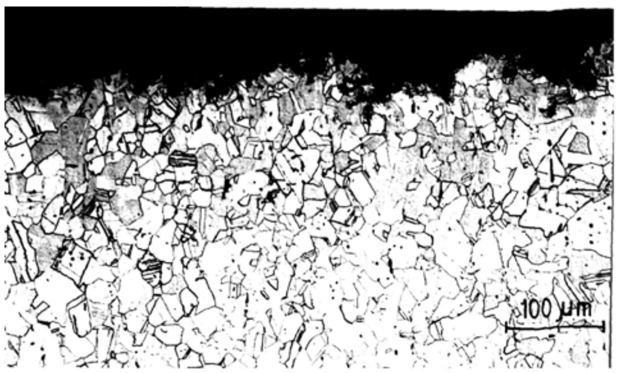

Fig.11 Optical microscopy of a cross section of the cavitated M63 brass specimen edge after a 6 hours test at the magnetostrictive rig of the University of Cape Town

3.2 DATA PROCESSING TECHNIQUE

The data obtained were carefully reviewed and processed in order to be presented in a standardised form in Part II of the Preliminary Report. The documentation of each *test series* (a series of tests conducted on the set of materials under specified test conditions at the specified facility) consists of :

- a copy of the Test Rig Identification Card
  which can be supplemented by additional schematics, drawings or photographs,
- Laboratory Results Summarisation Card which includes
  - values of parameters defining test conditions at the specified rig[1],
  - Test Series Summarisation Table,
  - averaged curves of cumulative volume loss and mean depth of penetration determined for all the materials tested in the series,
- documentation of all the *tests*[2] conducted in the series

The Test Series Summarisation Table comprises the following data:

- commercial name of each material tested,
- test duration,
- volume loss,
- eroded area,
- mean and maximum depth of erosion penetration,
- incubation periods,
- maximum and ultimate values of mean depth of penetration rates.

All the single-number parameters listed in the Test Series Summarisation Tables are averaged values. In case of different test durations for different materials, meantime values are added in order to compare erosion progress corresponding to the same exposure. Eroded area was usually specified by the contributor although in some cases it was needed to read it out of photographs. Mean depth of erosion penetration for each run was calculated by dividing the volume loss by the eroded area. Incubation periods $\tau_{0.2}$ and τ_{inc} are defined by an 0.2 mg mass loss and the tangent to cumulative volume loss curve at the inflection point, respectively.

Documentation of each test consists of :

- values of parameters defining test conditions,
- Test Summarisation Table,
- additional comments on test and data processing technique applied,
- list of enclosures,
- cumulative volume loss curves for each specimen,
- averaged mean depth of penetration curve,

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[1] These values may slightly differ from those given in the Test Rig Identification Card.

[2] Following the nomenclature adopted in this report and in the ICET database *a test* consists of a series of - - usually two - *erosion runs* of a specified material under specified cavitation conditions.

- averaged mean depth of penetration rate curve,
- optional data (enclosures) which can include:
  - microhardness distribution table (if available),
  - photograph(s) of eroded surface(s)
    (including those obtained by means of optical and/or scanning electron microscopy),
  - maximum depth of penetration curve,
  - metallographs (obtained by means of optical and/or scanning electron microscopy),
  - roughness profiles of eroded surfaces.

The Test Summarisation Table comprises all the erosion parameters listed already in the Test Series Summarisation Table. However, data for each specimen are given. The averaged values are shown below the Table.

The main part of the data processing work was conducted between 1989 and 1991. Due to scarce access to the professional software, all the curves were drawn manually. Averaging was conducted very carefully in order to provide for smooth shape of both the cumulative erosion and erosion rate curves which were also determined using traditional techniques. Merits and demerits of such a procedure can be a matter of discussion.

The author is conscious of diverse opinions on using the mean depth of penetration curves for comparative analysis of erosion test results. The main justification for this controversial technique[1] was physical significance attributed to the *MDP* (mean depth of penetration) and *MDPR* (mean depth of penetration rate) parameters. Both of them are directly correlated to the impingement intensity which allows to draw conclusions on dynamic features of the phenomenon. The controversy concerns definition of the eroded surface area. While the author of this report used the values given by the Contributors or read out from the photographs for each type of material, it is today his opinion that using a value determined for a soft reference material (e.g. an aluminium alloy) tested under the same conditions would be a better choice. However, in both cases a significant amount of freedom in determining the eroded area borders remains unavoidable. The problem will be suggested for discussion during the ICET Seminar.

In order facilitate the comparative analysis the Test Series Summarisation Tables as well as averaged volume loss and mean depth of penetration curves are reproduced in a concise form in the next section of this report.

[1] Such a technique was criticised by one of the Test Panel Members during the Second Cavitation Days Symposium held in Paris in March 1992.

3.3 ICET DATABASE SOFTWARE

The main purpose of developing the ICET database was to allow easy access to most of the source data delivered by the ICET Contributors. It is expected that such an access will facilitate independent interpretation and free discussion of the ICET results. There exists also a possibility to extend the database by additional data or to use its structure for the needs of other round robin tests.

Version 3.0/99 of the ICET database [16] comprises main data on contributing labs and test facilities involved, chemical composition and mechanical properties of test materials as well as erosion test results available both in form of exportable tables and volume loss vs time curves. The installation files are available at the diskettes attached to the *Experimental data* volume of this report and at the IMP PAN host computer under the *http:\\www.imp.gda.pl/ /icet* address. The installation files of the subsequent versions will be distributed in form of installation diskettes and through the *Internet* web. User's guide of the current database version is to be found in Appendix A of this report. Guides to the subsequent versions will be distributed together with the installation files.

It is assumed that subsequent versions will allow to generate and export reports and diagrams comprising data selected in form adjusted for further analysis by the user. It is also intended to include schematics of test facilities and photographs of eroded specimens. Due to substantial size (several hundred MB), files with digitised specimen photographs will be distributed solely through the *Internet* web and optionally appended to the database by the user.

The database has been developed as an application of the *Microsoft Access*™ *v.2.0* software using the *Microsoft Access Developer's Toolkit 2.* The runtime version of the database – delivered with the experimental data volume and available at the *www* page can be run directly from the *Microsoft Windows 3.1, Windows for Workgroups 3.11, Windows NT* and *Windows'95* level. The abridged version – available at a special wish – can be run solely in the *Microsoft Access* environment.

The ICET data are comprised in four main objects:

- *Laboratories*,
- *Materials*,
- *Rigs*,
- *Test*s,

and stored in a system of interrelated tables as described in [16]. All the main objects are accessible from the database *Control Panel* or the *Toolbar,* and can be viewed through a system of view boxes and diagrams.