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poświęcone są publikacjom naukowym z zakresu teorii i badań doświadczalnych w dziedzinie mechaniki i termodynamiki przepływów, ze szczególnym uwzględnieniem problematyki maszyn przepływowych

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exist for the publication of theoretical and experimental investigations of all aspects of the mechanics and thermodynamics of fluid-flow with special reference to fluid-flow machinery

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Investigation of Material Resistance to Cavitation within the International Cavitation Erosion Test Programme

Brief Note

1. ICET Background

Cavitation and cavitation erosion have been for years a source of numerous problems for those active in design and operation of hydraulic machinery and equipment. Today the phenomenon of cavitation remains still a major obstacle preventing further increase of hydraulic turbomachines capacity while keeping their size (read: manufacture and installation costs) constant. Deep concern with this state of the art is well reflected by the attention being paid to cavitation not only by the hydraulic machinery manufactures and users but also large national and international institutions as well as international scientific and technological conferences, just to mention ASME, ASTM, IAHR, IEC, ITTC, Naval Hydrodynamics Symposia, ELSI Conferences or numerous conferences on hydraulic machinery. State sponsorship of cavitation research programmes in numerous countries is also a manifestation of the significance being attributed to the problem.

Reduction of erosive cavitation effects in hydraulic machinery and equipment can be achieved, among others, by means of a proper selection of structural materials and the materials used for "postcavitation repairs". Such a selection requires knowledge of material resistance to cavitation, usually assessed in result of laboratory tests. It should be stressed that all the currently applied methods of assessment are relative ones – they consist in comparing cavitation damage on an actual material with that on a reference one and transferring the classification obtained onto the field conditions. However, results of such a procedure can be considered meaningful only in case of all material samples being tested under the same or similar test conditions. Furthermore, due to various relative resistance of materials under different cavitation loadings, test conditions should be close to those in the field.

In fact, there exists a wide variety of different methods used nowadays to test cavitation erosion resistance of material samples. Vibrative test rigs (with oscillating specimen and counter-specimen), cavitation tunnels (with a cavitator, modified venturi, barricade and counter-barricade), rotating disk and liquid jet impact facilities are still considered most widely spread [1, 2, 3]. However, some other test rigs, including cavitation jet facilities (Lichtarowicz cell [4], CAVIJET device [5]) and Lecoffre's cavitation vortex generator [6] are in more and more general use now.

It should be noticed here that the vibratory rig is the only facility subject to an internationally acknowledged ASTM standard [7] and several national standards [8]. The ASTM G-32 Standard, originally elaborated in result of a round-robin test carried out in 1969 [9, 10], has been already subject to several revisions and the latest, extensively revised, version is expected to be issued next year. The same procedure has been recently applied to the Lichtarowicz cell and an ASTM standard on cavitating jet test is currently being processed within the ASTM G-2 Committee [11].

While considering the current activity of the ASTM G-2 Committee extremely useful and hard to be overrated it is found also desirable to strive after a better insight into the possibility of correlating the standardized methods with other widely used approaches and to prepare a basis for development of further standards and recommendations.

Bearing this in mind the Institute of Fluid-Flow Machinery of the Polish Academy of Sciences (IMP PAN) has put forward an initiative of an International Cavitation Erosion Test (ICET) with the scope much wider than that of above mentioned round-robin tests. This initiative has found support of numerous specialists on cavitation erosion.

Table 1

List of materials subject to tests within the ICET Programme

Material	Designation
armco iron	E04
aluminium alloy	PA2
high quality carbon steel	45
acid resistant steel	1H18N9T
single-phase brass	M63
tarnamide plastics	polyamide 6

Table 2

Chemical composition of metallic test materials*, %

Chemical component	Material				
	E04	45	1H18N9T	M63	PA2
C	0.035	0.43	0.4	–	–
Mn	0.10	0.63	1.37	–	–
Si	0.01	0.26	0.55	–	–
P	0.026	0.030	0.030	–	–
S	0.035	0.033	0.010	–	–
Cr	–	–	17.6	–	–
Ni	–	–	9.40	–	–
Fe	rest	rest	rest	–	–
Cu	–	–	–	rest	–
Al	–	–	–	–	rest
others	–	–	Ti:0.60	Zn:32.6	Mg:2.7

* Chemical analysis has been carried out at the Institute of Structural Materials Technology and Welding, Technical University of Gdańsk.

Table 3

Heat treatment conditions of ICET metallic materials

Material	Heat treatment	Treatment conditions		
		temperature	duration	cooler
PA2	recrystallization annealing	250°C	30 min	air
M63	recrystallization annealing	550°C	30 min	air
E04	recrystallization annealing	600°C	20 min	air
45	hyperquenching	850°C	20 min	air
1H18N9T	heat refining	1050°C	15 min	water

Table 4

Mean values of mechanical properties (measured at the Institute of Structural Materials Technology and Welding, Technical University of Gdańsk)

Mechanical property	Material				
	PA2	M63	E04	45	1H18N9T
density*, kg/m	2693	8430	7853	7868	7886
hardness, HV_{10}*	71.7	80.9	108.4	192.8	191.0
tensile strength, MPa	208	352	328	721	605
yield point, MPa	169	117	263	419	225
modulus of elasticity, GPa	70	99	210	210	200
ultimate strain, %	17	65	40.5	22	52
cross section reduction at fracture %	63	72	72.5	39	64

* Measured at the SIGMA Research Institute, Olomouc,
** 10 kG load.

Table 5

Main physical parameters of polyamide 6 plastics

density, kg/m³	1162
relative viscosity of the solution	5
relative viscosity of the monomer, %	5
hardness, kG/cm²	1500
Vicat softening temperature, °C	205

Table 6

Statistics of cavitation erosion test rigs irvied in the ICET programme

Test rig kind	Number of facilities
vibratory rig	12
cavitation tunnel	7
rotating disk	4
cavitating jet	3
liquid impact facility	1
total	27

2. Test Objectives and Programme

The main objectives of the ICET are as follows:

* to compile data on design and operation of existing cavitation erosion rigs,
* to compare and correlate (as far as possible) the damage course and cavitation resistance assessments of selected groups of materials tested under different cavitation conditions,
* to determine the dependence between the damage course and the parameters defining test conditions of the materials tested,
* to work out the basis for further standardization of methods of evaluating material resistance to cavitation damage.

In order to specify properly the Test Programme and to make the best use possible of the results obtained a Test Panel consisting of 3 Co-ordinator's Representatives and 4 International Advisors has been established. The List of Panel Members is given in the appendix to this report.

The Test Programme, agreed with the Test Panel Members, covers tests on 6 materials listed in Table 1. The materials have been selected in a way providing evident differentation between their erosion curves – it can be easily noticed that two of them (E04 and PA2) are typical reference materials used in numerous erosion tests while the next three (45, 1H18N9T, M63) represent structural materials used commonly in engineering practice. All the metallic materials were acquired at the CENTROSTAL Steel Storehouse, the main distributor of metals in Poland; the polyamide 6 plastics was obtained from the CHEMIPLAST EVG in Gliwice. Chemical composition, heat treatment conditions and values of some mechanical parameters of metallic materials are given in Tables 2, 3 and 4 while the main physical parameters of polyamide 6 are to be found in table 5.

Test Participants have been asked to conduct erosion tests at at least 2 specimens of each kind under specified steady state conditions. As usual the tests should continue as long as needed in order to attain the steady-state damage period. The results submitted on Measurement Cards comprise main operating parameters of the facility as well as the tables of mass/volume losses in course of the test, final values of mean and maximum depth of pits, data on microhardness distribution, photographs of damaged surfaces and their metallographical structure. Following suggestions of some International Advisors the Participants have been encouraged to supplement data obtained under standard conditions by those resulting from modification of the test parameters.

The acceptance of Test Rig Identification was completed in the beginning of 1989. Till the fall of 1991 results of experimental tests are expected. The Preliminary Report to be issued by the end of 1991 will form a basis for discussion of test results at ICET Seminar to be organized next year. The main conclusions following from the ICET Programme will be summarized in the Final Report.

3. Test Participants and Facilities Involved

Following the Call for Test Rig Data distributed among over 100 Potential Test Participants and the next announcements issued in 1988 and 1989, 17 laboratories have confirmed their participation in the ICET Programme (cf. the List of Active Test Participants given in the appendix to this report)

It can be easily seen from the statistics given in Table 6 that a substantial number of tests within the ICET programme will be carried out on vibratory rigs. The vibration frequency of these facilities is usually close to 20 kHz which corresponds to the ASTM G-32 Standard. An exception in this respect is the laboratory of the Institute of Fluid-Flow Machinery of the Polish Academy of Sciences (IMP PAN) equipped with a facility of 8 kHz vibration frequency. Much wider diversity can be noticed in vibration amplitudes, sizes and mounting methods of test samples. Counter-samples are applied in two labs (University of Cape Town and University of Hull). This technique enables testing brittle materials. In other laboratories the specimen buttons are usually screwed in the horn (following the ASTM G-32 Standard). A specimen screwed on the horn is applied in Czechoslovakia (following the Czechoslovakian Standard CSN-015082-76) whereas a solution with a specimen mounted with a special nut (Polish Standard PN-86/H-04427) is applied only in the IMP PAN.

Cavitation tunnels involved in the ICET programme show a significant variability in the test chamber design. Tests are conducted on 3 tunnels with cylindrical cavitators (Chinese Ship Scientific Research Centre in Wuxi, Institute of Water Problems of Bulgarian Academy of Sciences in Sophia and the Hohenwarte Pumped-Storage Power Plant in East Germany), one tunnel with a wedge cavitator (City University in London), one tunnel with a cavitating venturi (Tsinghua University, Beijing) and two tunnels with barricades and counter-barricades (University of Hiroshima and University of Hannover). The majority of cavitation tunnels are not used for tests of highly resistant materials (like stellites). Only non-ferrous alloys are tested at the CSSRC*). Routine cavitation resistance tests for industrial needs are known to be carried out at the University of Hannover.

From among four rotating disks involved in the ICET project two facilities are of the similar design. Both in the CSSRC and the SIGMA Research Institute (Olomouc, Czechoslovakia) cavitation is generated by holes drilled in the disk upstream of the test samples. Cavitators in form of cylindrical bolts are applied in the IMP PAN and the KSB laboratory in Frankenthal (West Germany). However, the samples are mounted at the disk in the IMP PAN and on the braking vanes at the KSB lab.

The best coincidence is kept among the cavitating jet facilities. All of them are based on Dr. A. Lichtarowicz design, currently standardized by the ASTM.

There will exist also a possibility to compare results coming from all the above mentioned rigs with those obtained at a liquid impact test facility. Liquid impact tests will be carried out in the SIGMA Research Institute in Olomouc.

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*) Chinese Ship Scientific Research Centre, Wuxi (China).

The information given above proves that although only a small fraction of labs active in the field of cavitation resistance tests has declared to take part in the ICET programme (no application has been received from the USSR), test rigs of the most common designs will be involved in the project in a number which should enable achievement of the basic ICET aims.

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Appendix

Test Panel

Co-ordinator's Representatives

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Dr. Janusz Steller, IMP PAN, Gdańsk
Dr. Tadeusz Krzysztofowicz, Technical University of Gdańsk

International Advisors

Prof. Andrzej Lichtarowicz, University of Nottingham, U.K.
Prof. Hartmut Louis, University of Hannover, Germany
Prof. Marian Mazurkiewicz, University of Missouri, Rolla, U.S.A.
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Test Participants

* Bulgarian Academy of Sciences, Institute of Water Problems, SOFIA, Bulgaria
* China Ship Scientific Research Institute, WUXI, China
* Tsinghua University, BEIJING, China
* College of Mining and Metallurgy, OSTRAVA, Czechoslovakia
* Sigma Research Institute, OLOMOUC, Czechoslovakia
* Pumped Storage Power Plants, Socialized Establishment, DRESDEN, Germany
* University of Hannover, HANNOVER, Germany
* KSB A.G., FRANKENTHAL, Germany
* Fluid Control Research Institute, PALGHAT, India
* CISE S.p.A., MILANO, Italy
* Hiroshima University, HIGASHI-HIROSHIMA, Japan
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