4.5 COMPARATIVE ANALYSIS

4.5.1 Test facilities

One can consider a laboratory method of assessing material resistance to cavitation valid for industrial applications if the damage rate at the test rig is substantially higher than that in the field, but the ratio between volume losses of typical structural materials is kept unchanged. Unfortunately, strict fulfilment of this requirement is not possible due to the following reasons:

- the ratio of damage rates of different materials depends on the cavitation loading,
- the realistic loading of the material under field conditions is usually unknown,
- laboratory tests are conducted under cavitation loading conditions differing from those in the field not only in the frequency of cavitation pulses, but also their amplitude distribution, duration and the surface area impinged.

As already mentioned, flow cavitation rigs – cavitation tunnels and rotating disks – are generally considered to model cavitation conditions in a hydraulic machine better than other test facilities. Their main disadvantage is that rigs with relatively high damage rate are very expensive in erection and operation. Therefore the prospects of their effective standardisation can be considered rather doubtful.

In order to compare rigs of different principle of operation, erosion progress at their representatives has been put together in Fig.32. The criterion used when selecting the representative rigs (Table 20) was conformity with existing standards and high erosion rate.

Table 20 Representative cavitation erosion test rigs

Principle of operation	Identifier	Laboratory	Operating parameters[1]
Vibratory rig (vibrating specimen)	VRV	CISE	frequency: 20 kHz, p-p amplitude: 50 μm
Vibratory rig (stationary specimen)	VRS	CAP	frequency: 20 kHz, p-p amplitude: 60 μm, specimen/horn distance: 0.35 mm
Rotating disk	RD	IMP	peripheral velocity: 42.5 m/s pressure: 255 kPa
Cavitation tunnel (cylindrical bolt)	CTC	PEITZ	upstream pressure: 1033 kPa, inlet velocity: 30 m/s
Cavitation tunnel (system of barricades)	CTB	HAN	upstream pressure: 1000 kPa, downstream pressure: 50 kPa
Cavitating jet cell	CJ	HAN	upstream pressure: 19 MPa, downstream pressure: 0.1 MPa, stand-off distance: 18 mm
Liquid jet facility	LJ	SIGMA	nozzle diameter: 6 mm, jet velocity: 6.75 m/s, specimen velocity: 80 m/s

[1] All pressures are given in absolute units.

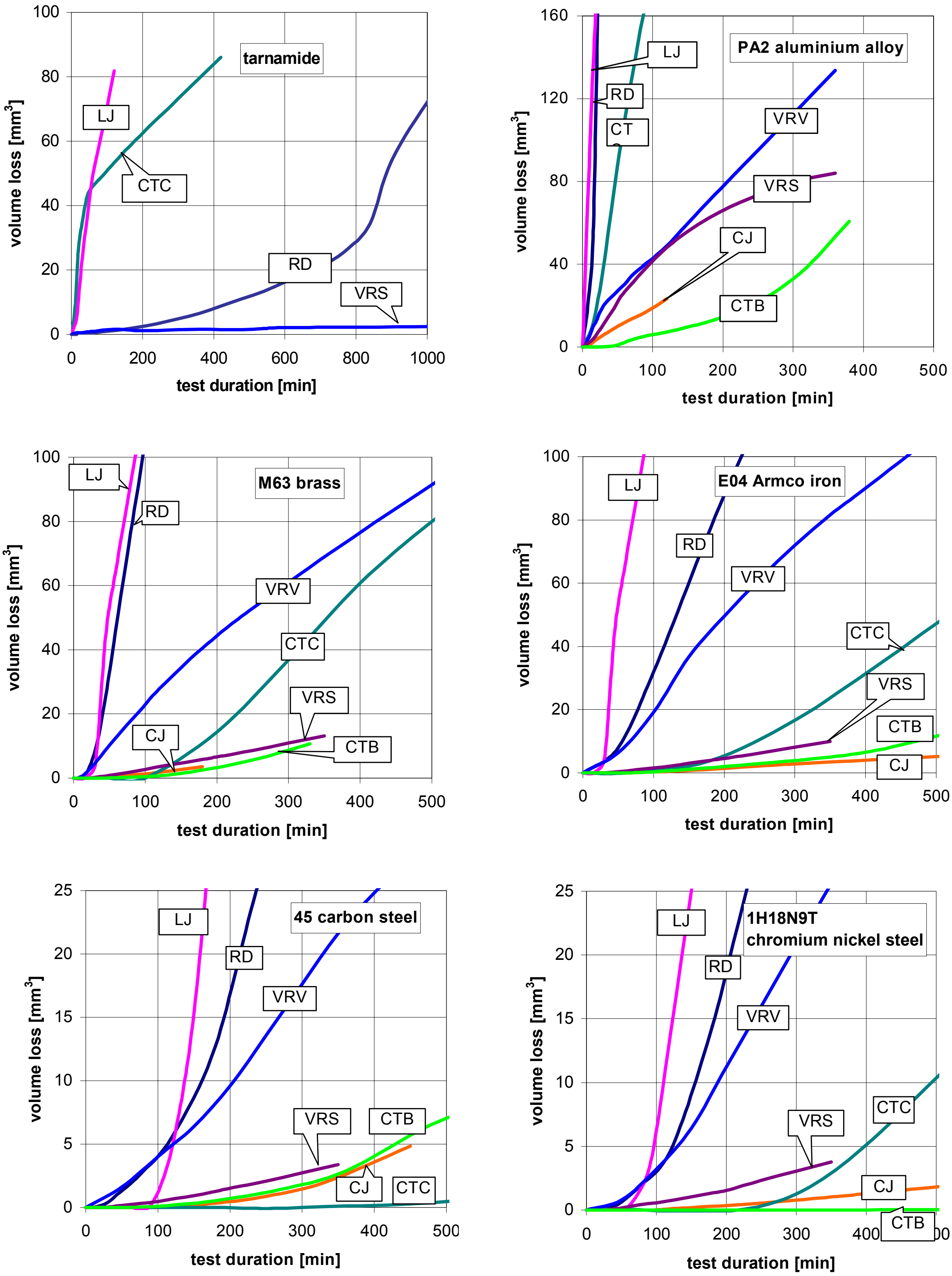


Fig.32 Cumulative volume loss curves of the ICET test materials tested at the selected cavitation rigs

It can be seen from Fig.32 that in all the cases the highest erosion rate was observed at the liquid jet facility (LJ) in Olomouc (SIGMA). It is worthwhile to notice that both at this facility and the CTC cavitation tunnel in Hohenwarte (PEITZ) there is practically no incubation period for the tarnamide plastics which suggests different erosion mechanism than that at the IMP PAN rotating disk (RD). The fall of volume loss rate in PEITZ after half an hour of erosion test can be due to the following reasons:

- increase of water absorption by the eroded specimen,
- change of effective cavitation loading due to the change of eroded surface geometry.

A characteristic feature of the PEITZ tunnel is a decrease of the erosion rate (as related to that of other rigs) with falling tensile strength and yield point value of metallic materials. A clear evidence of the above is comparison of the 45 and 1H18N9T curves determined in the CTB (Hannover) and CTC (Hohenwarte) tunnels. High erosion rate of the tarnamide plastics and relatively high erosion rate of the 1H18N9T steel suggest a major fraction of powerful pulses in the cavitation loading structure. However, this loading appears insufficient to erode substantially the 45 carbon steel even after 8 hours of test duration. Due to extremely long incubation period (cf. Table 13), one may suppose that the fraction of pulses responsible for fatigue erosion of the 45 steel is relatively small at this facility.

Erosion rates of the PA2 and M63 alloys tested at the rotating disk (RD) rig in the IMP PAN lab are very close to those obtained at the liquid jet facility (LJ) in Olomouc. For other test materials the ratio of erosion rates exceeds the factor of 2. Nevertheless, the rotating disk of the IMP PAN lab can be considered a highly efficient cavitation resistance test facility.

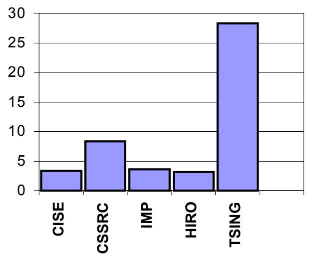
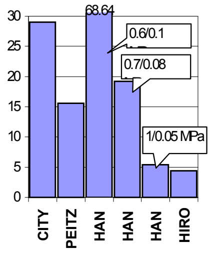
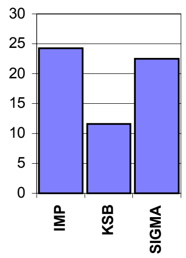
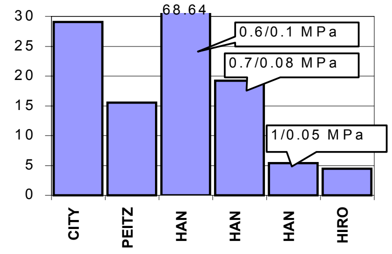
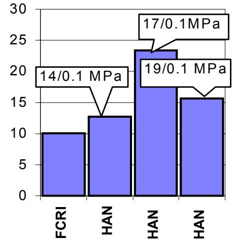
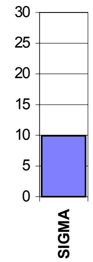
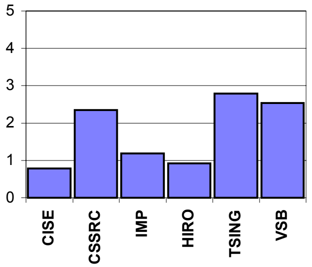
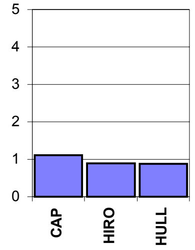
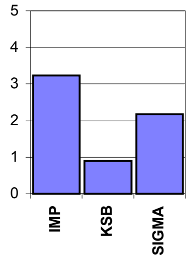
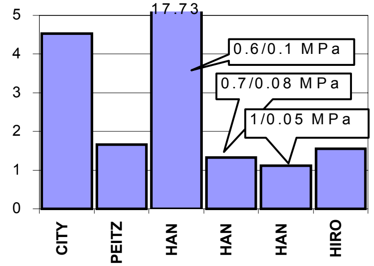
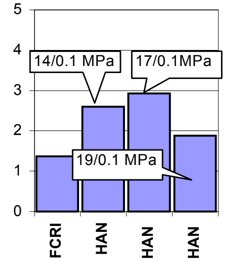
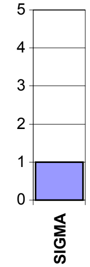
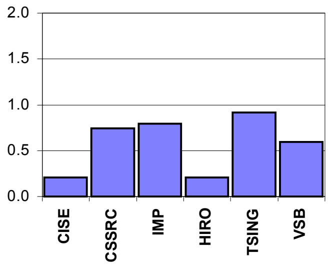
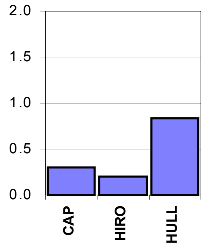
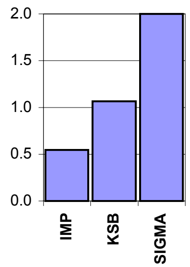
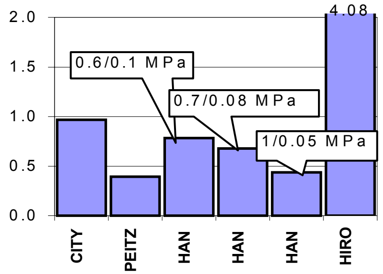
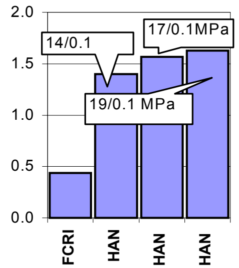
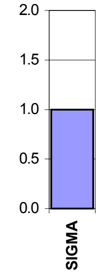
It is worthwhile to notice that the CISE vibratory rig (VRV), “keeps the pace” with the highly efficient LJ/RD pair. This is especially the case for highly resistant 45 and 1H18N9T steels for which all other rigs show substantially smaller rate of damage.

In order to compare globally the differentiation of material performance at different test rigs, a set of diagrams of the relative maximum instantaneous erosion rate ier_{E04} = $= IER_{max}/IER_{max,\ E04}$ has been plotted in Table 20. In some cases the scatter of results is increased by the fact that the maximum erosion rate was not attained and the *IER* value at the end of the test had to be used instead. Nevertheless, even if these cases are excluded from consideration, it can be seen from the rest of Table 20 that quantitative assessments of relative material resistance based on the relative IER_{max} value can be very ambiguous. The highest differentiation of results is observed in cavitation tunnels which are historically prototypes of all the other rigs, usually considered to resemble especially well cavitation loading conditions in the field. In case of the HAN tunnel a clear correlation between the cavitation development degree (as measured by the cavitation number) and the ier_{E04} value can be stated. This is not always the case for cavitating jet cells despite the general trend of falling IER_{max} value with rising cavitation number (Fig.31).

In case of some rigs characterised by rather low cavitation intensity (TSING vibratory rig and HAN cavitation tunnel with 0.6 MPa upstream pressure) very high relative erosion rate of soft materials (PA2, M63) is attained. On the other hand side, very low relative erosion rate of highly resistant materials can be sometimes observed at rigs with very high cavitation intensity. Thus low cavitation intensity rigs seem better suited to test soft materials while the high intensity rigs should be recommended to test highly resistant ones. Any far going conclusions on correlation between cavitation intensity and erosion rate seem to require detailed analysis of the distribution of cavitation pulses at the eroded surface.

The analysis based on the CER_{max} value leads to lower differentiation of results. Unfortunately, due to relatively short test duration, such an analysis has to be confined to a limitetd number of rigs.

Table 21 Maximum values of the instantaneous erosion rate related to that of the E04 Armco iron

material	Vibratory rigs		Rotating disks	Cavitation tunnels	Cavitating jet	Liquid jet
PA2						
M63						
45						
1H18N9T