## 4.3 CAVITATION TUNNELS

Tests in cavitation tunnels reveal erosion rate differences up to 3 orders of magnitude. Severe cavitation conditions are obtained in the Hohenwarte II Pumped Storage Power Plant (PEITZ) and the City University (CITY) labs (Table 14, Fig.23, 24). The volume loss rate of PA2 aluminium alloy in PEITZ lab is over 2000 higher than that in the CSSRC. The ratio of erosion rates of M63 brass in PEITZ and CITY to that in the CSSRC is about 200 (Fig.25).

Severe cavitation conditions in PEITZ lab lead also to high damage rate of the polyamide 6 (tarnamide) specimens and relatively poor performance of the 1H18N9T steel (erosion rate twice as high as that of the 45 carbon steel). The factor essentially responsible for high erosion rate is surely very high velocity of the undisturbed flow (over twice as high as that in CSSRC).

Intense cavitation in the CITY tunnel is surely due to the proper selection of both the cavitator and the operating parameters. In fact, one should expect a triangular wedge applied here to generate very intense cavitating vortices. The differentiated ratio of erosion rates in CITY and PEITZ (Fig.24) is a proof of essentially different structure of cavitation impingement in these labs. Due to lack of data on eroded area in the PEITZ tunnel and the maximum depth of erosion in the CITY lab, it is not possible to compare the local intensities of cavitation. However, by comparing the ratios of PA2 and M63 volume loss and the *MDP* values in CITY and CSSRC (Fig. 25) one can see that concentration of damage downstream the wedge in CITY is higher than that in the CSSRC. This is especially the case for the more resistant materials[1]. One can easily notice that while cavitation number

$$K = \frac{p_u - p_v}{0.5\rho v^2}$$

is 2.05 in CSSRC; it is twice higher in the CITY lab. However, flow velocity in London is by 50 % higher than that in Wuxi. It can be supposed that cavitation pulses in the CSSRC are therefore much softer than those at the City University in London.

Due to cavitating vortices orientation, damage concentration in tunnels with single obstacle (wedge or bolt) cavitators is usually expected to be higher than that in tunnels with a system of barricades. A clear confirmation of this general rule are the ratios of the cumulative maximum depth of penetration rate (*CMaxDPR*) and the cubic root of the cumulative erosion rate (*CER*) in PEITZ to those in the HIRO cavitation tunnel (Table 15). Worthwhile to notice are low values of *CER* ratio for materials expected to show high cavitation resistance.

The results from Hiroshima show a completely unexpected ordering of materials (Table 15d, Fig.26). Following Professor M.Matsumura [18], this effect can be attributed to cavitation/corrosion interaction which is confirmed by a sudden bending of the depth of damage curves in Fig.27[2]. The curves in this figure show much better coincidence with results from other labs than the cumulative volume loss curves in Fig.26.

[1] Please confer photographs in Part II of this report.

[2] As explained in [19], the depth of damage parameter was determined at a fixed point, as a distance between the profiles of the original surface and that of the damaged surface, measured with a surface roughness meter.

**Table 14a Test Series Summarisation Table of the CITY cavitation tunnel (cavitator: wedge, inlet pressure[1]: 879 kPa, inlet velocity: 21 m/s)**

| *material* | *test duration* | *volume loss* | *eroded area* | *incubation period* | *$MDPR_{max}$* |
|---|---|---|---|---|---|
| | min | $mm^3$ | $mm^2$ | min | µm/min |
| PA2 | 150 | 158.06 | 398 | 12 | 2.010 |
| M63 | 240 | 22.46 | 168 | 66 | 0.742 |
| E04 | 550 | 9.05 | 83 | 213 | 0.332 |
| 45 | 600 | 6.10 | 84 | 367 | 0.317 |
| 1H18N9T | 550 | 2.86 | 86 | 351 | 0.152 |

**Table 14b Test Series Summarisation Table of the CSSRC cavitation tunnel (cavitator: wedge, inlet pressure[1]: 103 kPa, inlet velocity: 14 m/s)**

| *material* | *test duration* | *volume loss* | *eroded area* | *incubation period* | *$MDPR_{max}$* |
|---|---|---|---|---|---|
| | min | $mm^3$ | $mm^2$ | min | µm/min |
| PA2 | 1400 | 1.910 | 685 | 172 | 0.0023 |
| M63 | 1400 | 0.712 | 712 | 70 | 0.0013 |

**Table 14c Test Series Summarisation Table of the PEITZ cavitation tunnel (cavitator: bolt, inlet pressure[1]: 1030 kPa, inlet velocity: 30 m/s)**

| *material* | *test duration* | *volume loss* | *eroded area[2]* | *incubation period* | *$MDPR_{max}$* |
|---|---|---|---|---|---|
| | min | $mm^3$ | $mm^2$ | min | µm/min |
| PA2 | 150 | 287.0 | 986.3 | 14 | 2.350 |
| M63 | 720 | 115.1 | 986.3 | 132 | 0.250 |
| E04 | 1020 | 101.9 | 986.3 | 200 | 0.151 |
| 45 | 4035 | 142.3 | 986.3 | 1000 | 0.059 |
| 1H18N9T | 3780 | 110.3 | 986.3 | 360 | 0.050 |
| tarnamide | 420 | 101.9 | 986.3 | 5 | 2.860 |

[1] absolute value

[2] the total surface area of the specimen

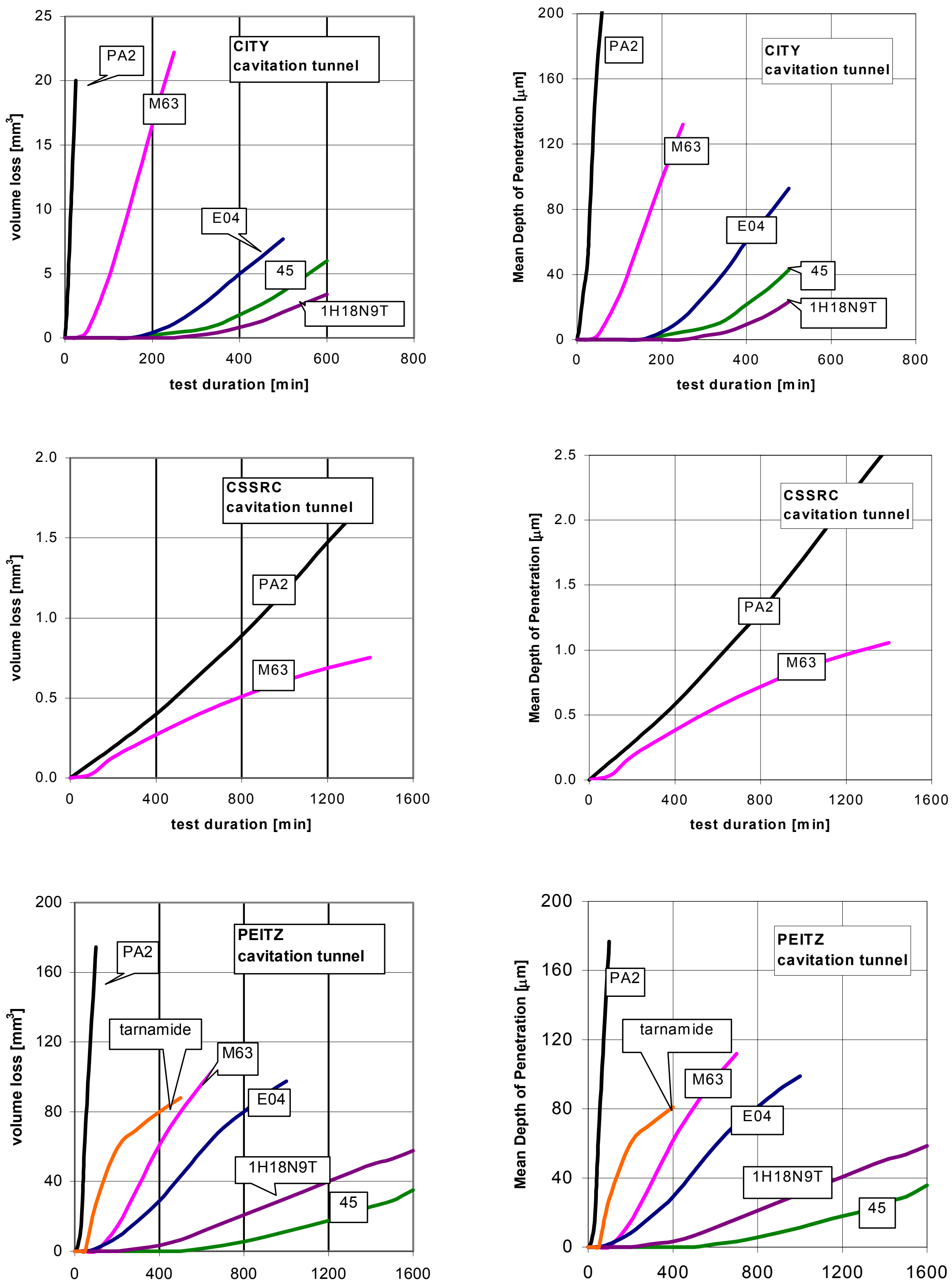


**Fig.23 Cumulative volume loss and *MDP* curves of the ICET materials tested in cavitation tunnels with bolt and wedge cavitators**

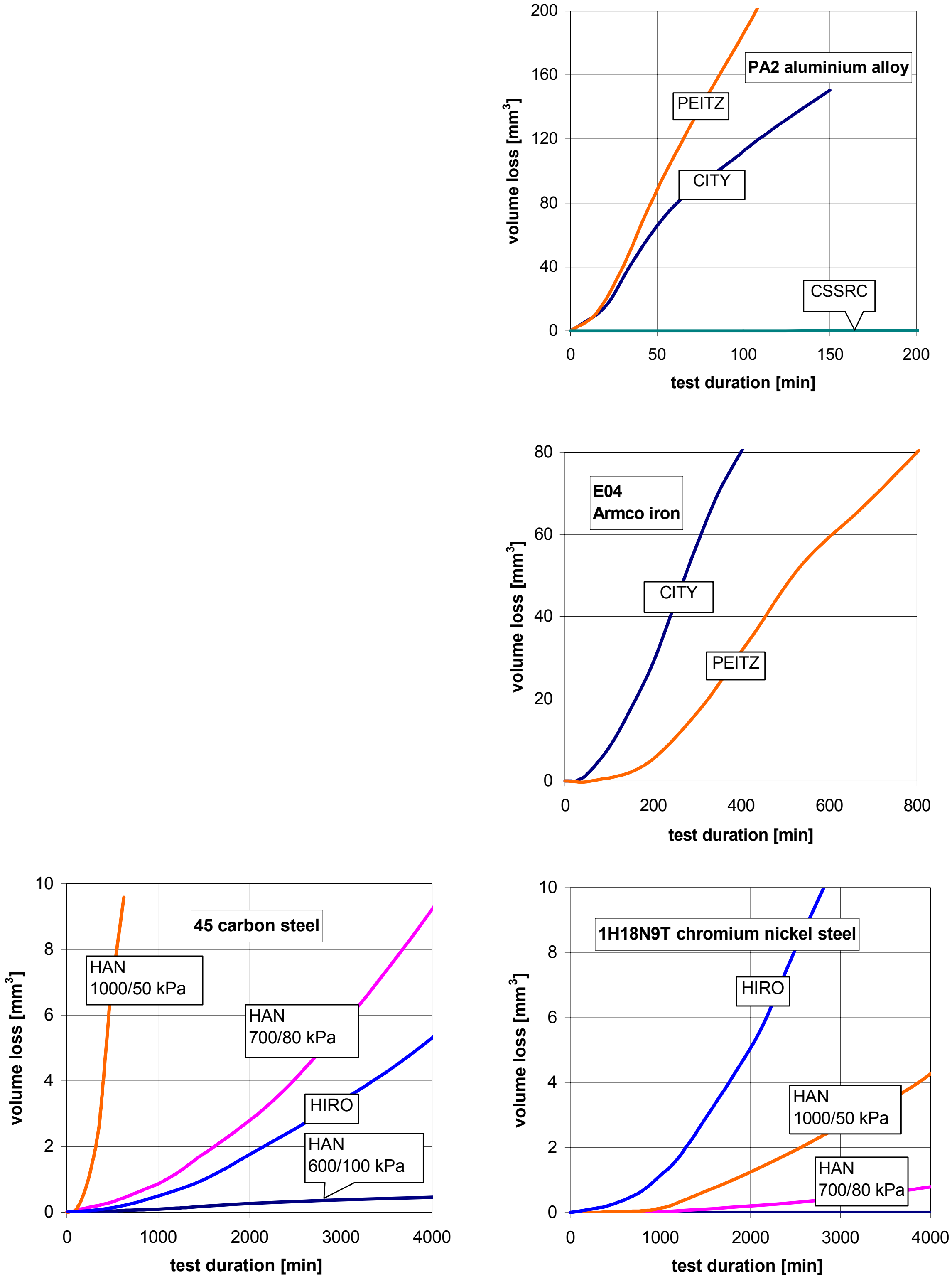


**Fig.24 Cumulative volume loss curves of the ICET materials tested in cavitation tunnels with bolt and wedge cavitators**

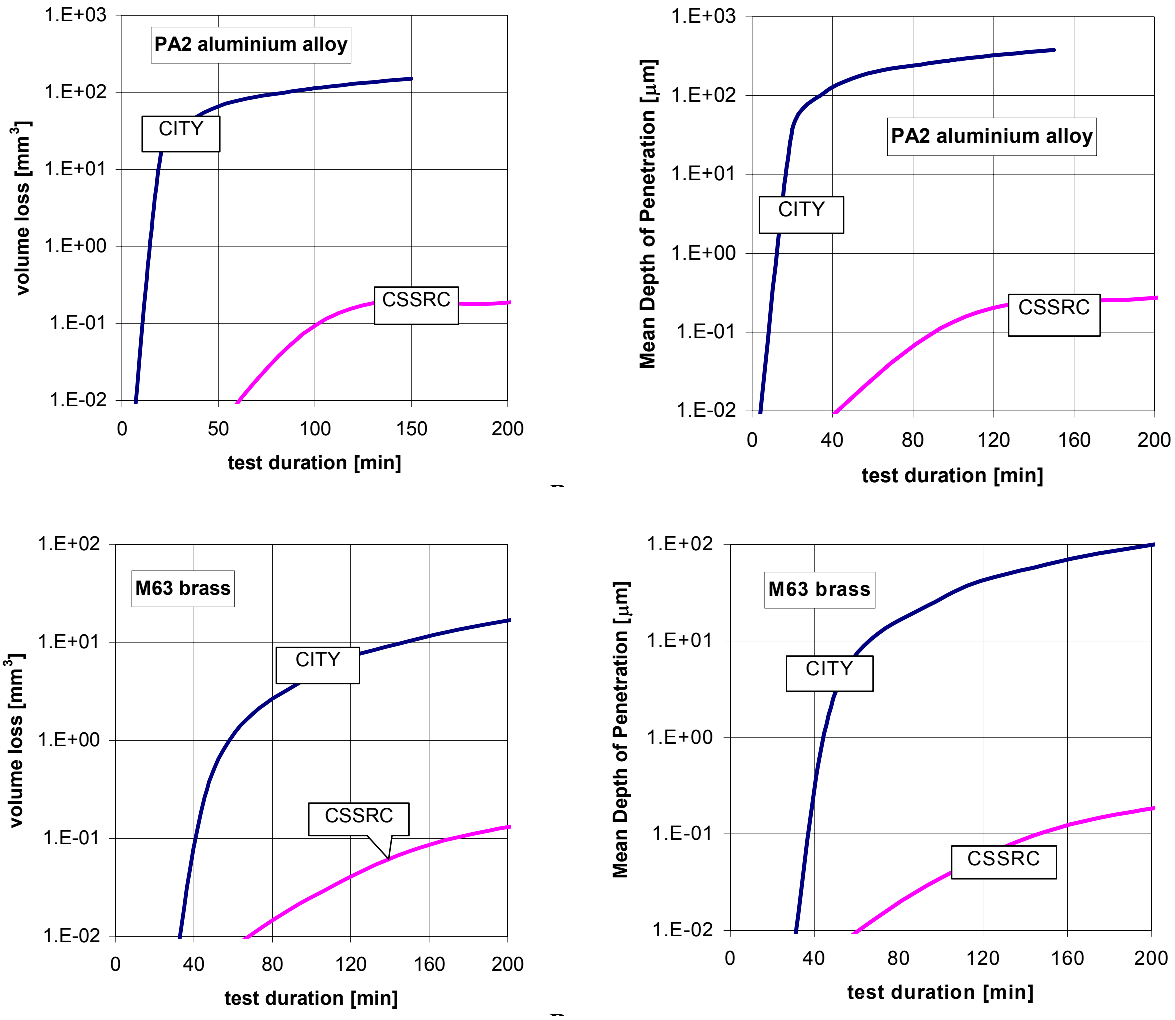


**Fig.25 Cumulative volume loss and the *MDP* curves of PA2 alloy and M63 brass tested in CITY and CSSRC cavitation tunnels**

**Table 15 Cumulative maximum depth of penetration rate (*CMaxDPR)* and the cumulative erosion rate[1] (*CER)* in PEITZ related to those in the HIRO cavitation tunnel**

| material | *CMaxDPR* | *CER* | $CER^{1/3}$ |
|---|---|---|---|
| PA2 | 45.7 | 386.7 | 7.3 |
| M63 | 99.7 | 73.0 | 4.2 |
| E04 | 79.5 | 69.0 | 4.1 |
| 45 | 4.3 | 9.1 | 2.1 |
| 1H18N9T | 12.3 | 4.7 | 1.7 |
| tarnamide | 857.4 | | |

[1] at the end of a test

**Table 16a Test Series Summarisation Table of the HAN cavitation tunnel (barricades system, upstream pressure[1]: 600 kPa, downstream pressure[1]: 100 kPa)**

| *Material* | *test duration* | *volume loss* | *eroded area* | *incubation period* | *$MDPR_{max}$* |
|---|---|---|---|---|---|
| | min | $mm^3$ | $mm^2$ | min | nm/min |
| PA2 | 6932 | 24.991 | 1800 | 3183 | 15.10 |
| M63 | 2446 | 9.312 | 1800 | 1167 | 3.90 |
| E04 | 38348 | 11.83 | 1800 | 3500 | 0.22 |
| 45 | 24665 | 5.516 | 1800 | 9250 | 0.1725 |
| 1H18N9T | 104212 | 3.411 | 1800 | 22667 | 0.041 |

**Table 16b Test Series Summarisation Table of the HAN cavitation tunnel (barricades system, upstream pressure[1]: 700 kPa, downstream pressure[1]: 80 kPa)**

| *Material* | *test duration* | *volume loss* | *eroded area* | *Incubation period* | *$MDPR_{max}$* |
|---|---|---|---|---|---|
| | min | $mm^3$ | $mm^2$ | Min | nm/min |
| PA2 | 430 | 37.950 | 1800 | 135.0 | 71.00 |
| M63 | 2040 | 12.123 | 1800 | 779.1 | 4.90 |
| E04 | 2550 | 12.950 | 1800 | 683.3 | 3.70 |
| 45 | 4885 | 12.748 | 1800 | 1616.6 | 2.50 |
| 1H18N9T | 8428 | 2.37 | 1800 | 2633.0 | 0.31 |

**Table 16c Test Series Summarisation Table of the HAN cavitation tunnel (barricades system, upstream pressure[1]: 1000 kPa, downstream pressure[1]: 50 kPa,)**

| *Material* | *test duration* | *volume loss* | *eroded area* | *incubation period* | *$MDPR_{max}$* |
|---|---|---|---|---|---|
| | min | $mm^3$ | $mm^2$ | min | μm/min |
| PA2 | 380 | 60.75 | 1800 | 276.7 | 0.2150 |
| M63 | 370 | 13.9 | 1800 | 192.5 | 0.0445 |
| E04 | 600 | 18.25 | 1800 | 401.7 | 0.0400 |
| 45 | 623 | 9.58 | 1800 | 280.0 | 0.0175 |
| 1H18N9T | 7912 | 13.949 | 1800 | 2050.0 | 0.0013 |

[1] absolute value

**Table 16d Test Series Summarisation Table of the HIRO cavitation tunnel (barricades system, upstream pressure[1]: 506 kPa)**

| *Material* | *test duration* | *volume loss* | *eroded area* | *incubation period* | $MDPR_{max}$ |
|---|---|---|---|---|---|
| | min | $mm^3$ | $mm^2$ | min | µm/min |
| PA2 | 1140 | 5.64 | 142.7 | 435 | >0.055 |
| M63 | 12300 | 26.93 | 195.6 | 2200 | 0.014 |
| E04 | 11150 | 16.15 | 93.0 | 3330 | 0.019 |
| 45 | 7500 | 29.05 | 114.5 | 3300 | 0.063 |
| 1H18N9T | 8000 | 50.05 | 91.0 | 2350 | 0.093 |

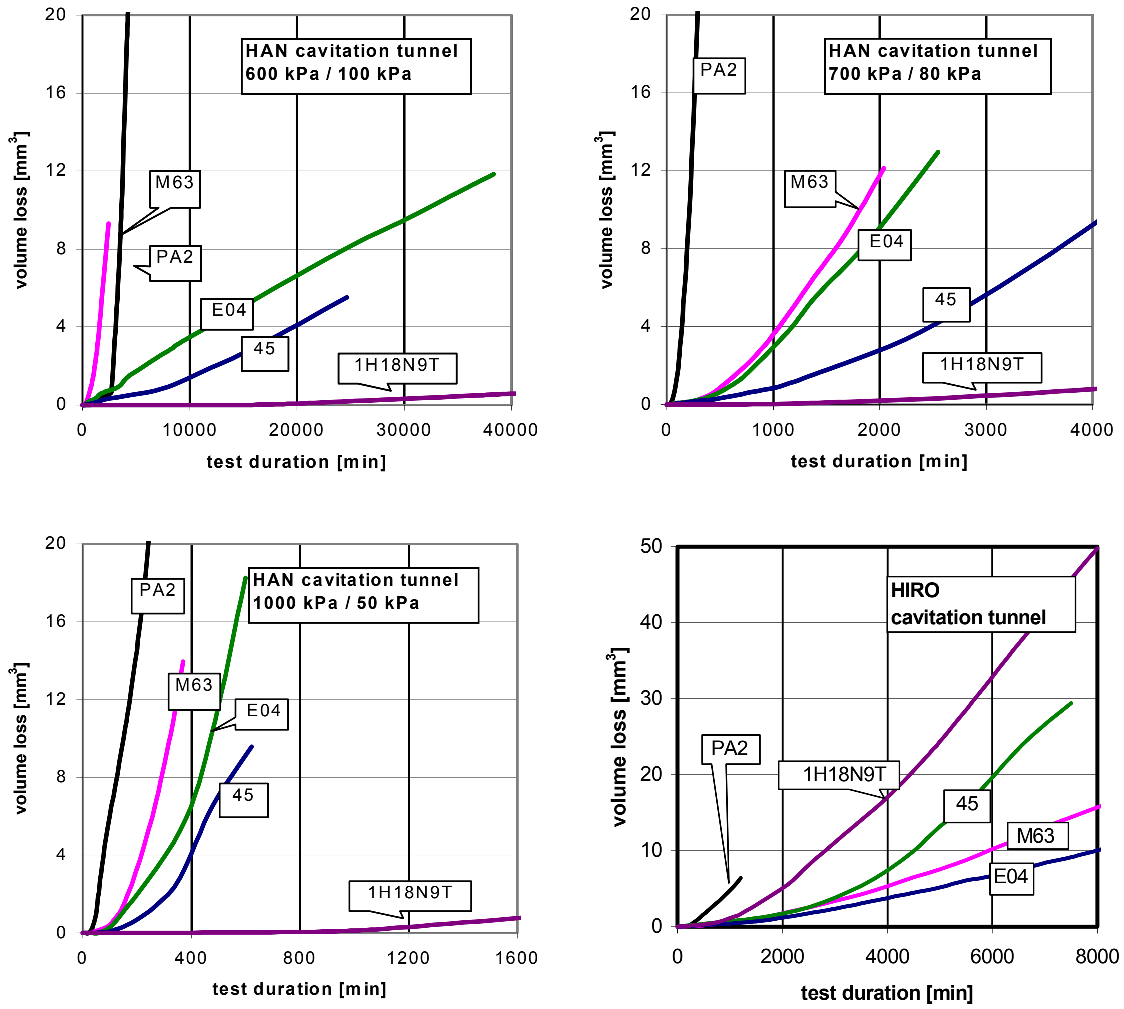


**Fig.26 Cumulative volume loss curves of the ICET materials tested at the cavitation tunnels with barricade systems**

[1] absolute value

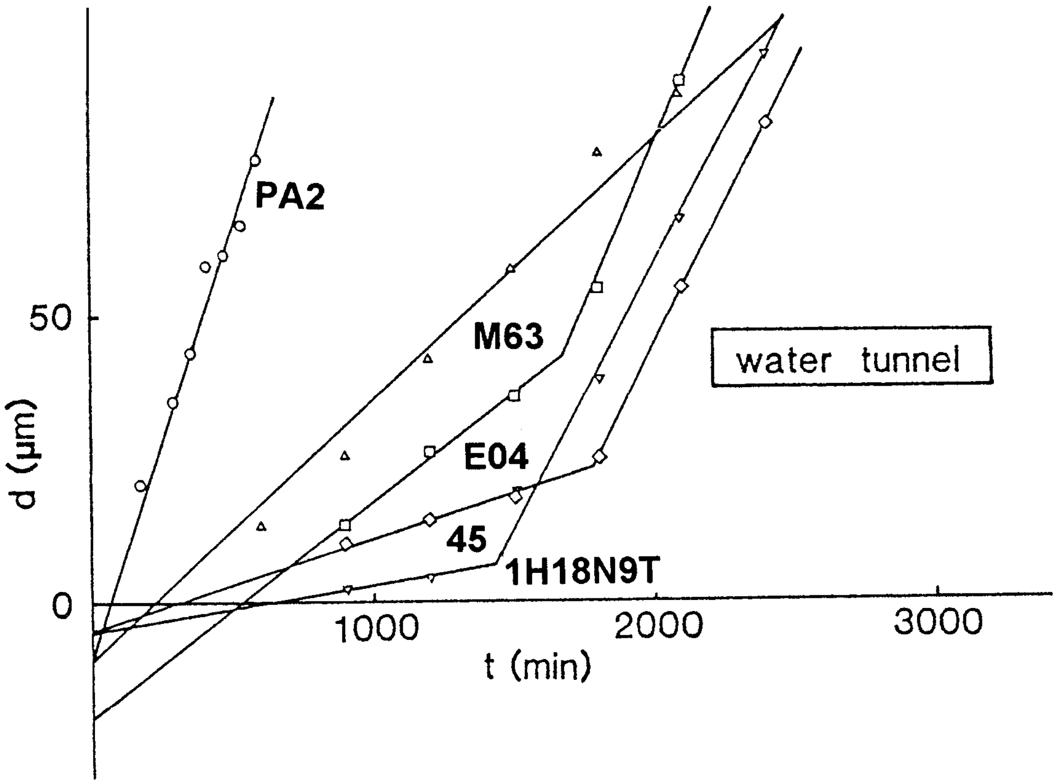


**Fig.27 Depth of damage curves in the HIRO cavitation tunnel [18,19]**

The results obtained in the University of Hannover (Table 16a,b,c, Figs.28,29) give an excellent opportunity to follow the erosion rate dependence on the cavitation number

$$K' = \frac{p_u - p_v}{p_u - p_d}$$

in an Erdmann-Jessnitzer test chamber. It can be seen from Table 17 that a change of the cavitation number between 1.05 and 1.20, results for most materials in the two orders of magnitude change of the maximum erosion rate.

**Table 17 Maximum values of the instantaneous erosion rate , $mm^3/h$, in the Erdmann-Jesnitzer test chamber of the HAN cavitation tunnel**

| *material* | ***K'* = 1.05** | **1.13** | **1.20** |
|---|---|---|---|
| PA2 | 23.220 | 7.668 | 1.6308 |
| M63 | 4.806 | 0.529 | 0.4212 |
| E04 | 4.320 | 0.400 | 0.0238 |
| 45 | 1.890 | 0.270 | 0.0186 |
| 1H18N9T | 0.140 | 0.033 | 0.0044 |

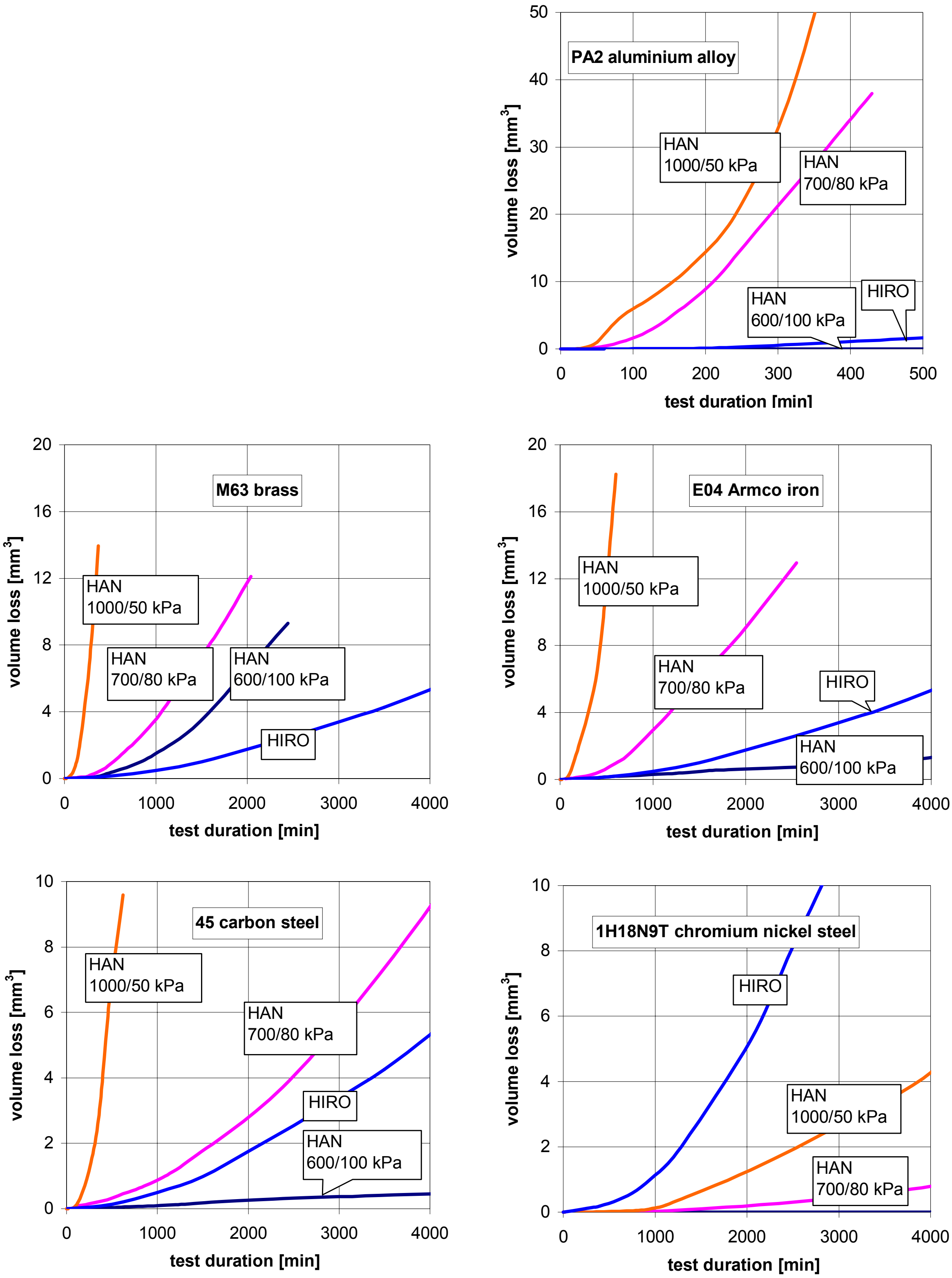


**Fig.28 Cumulative volume loss curves of the ICET materials tested in cavitation tunnels with barricade systems**