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Correlating inertial acoustic cavitation emissions with material erosion resistance

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Pós MQI PUC-Rio
Pós-Graduação em Metrologia
Qualidade · Inovação · Sustentabilidade

NPL
National Physical Laboratory

Presentation roadmap

The context

Cooperation

[3] Ibanez I., MSc Dissertation, Measurement and influence of cavitation induced by ultrasonic on erosion of engineering materials (in Portuguese), Postgraduate Programme in Metrology (PósMQI), Rio de Janeiro, RJ, BRAZIL, 2014.

Experimental work *developed by a postgraduate student of the Brazilian Metrology Programme in the Acoustics Laboratory of the National Physical Laboratory (NPL/UK)*

Correlating inertial acoustic cavitation emissions with material erosion resistance

Main interest:

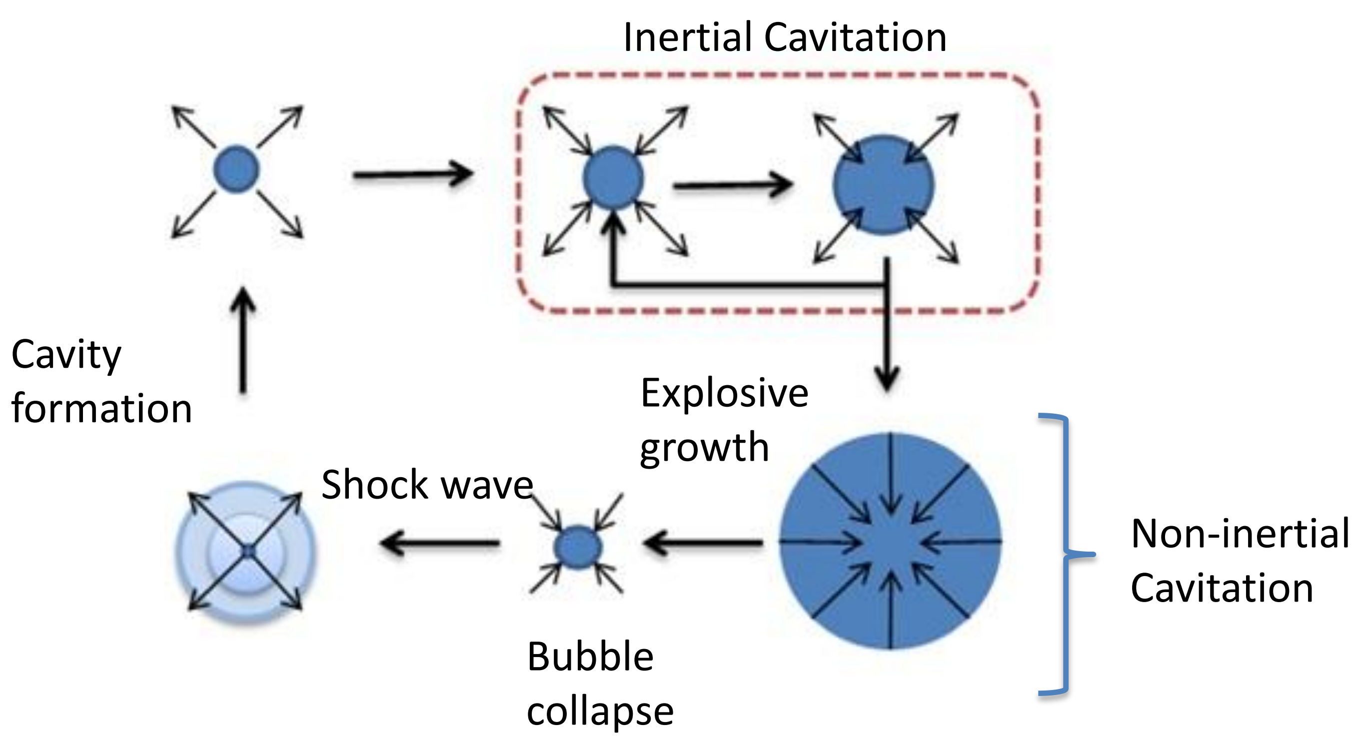
To study cavitation erosion on engineering materials

This work:

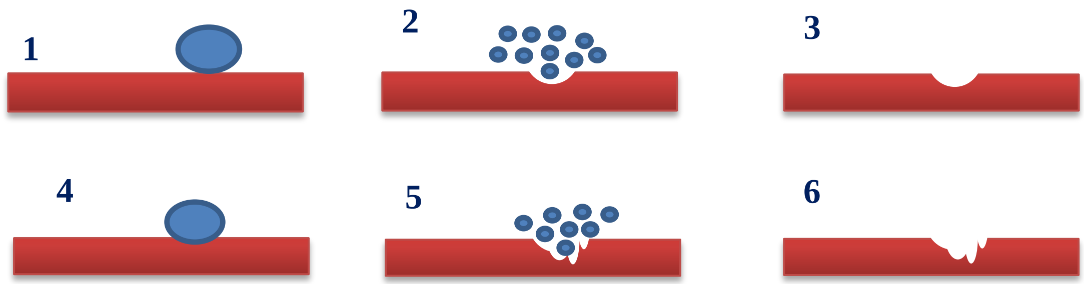
Cavitation erosion on Aluminium-Bronze

Cavitation induced by an acoustic medium

Occurs when an acoustic wave propagates in a fluid experimenting a reduction in pressure (rarefaction) with respect to the saturation vapour pressure.



Cavitation erosion: *a gradual loss of material from a solid surface due to its continuous exposure to cavitation [ASTM G32-2010]*

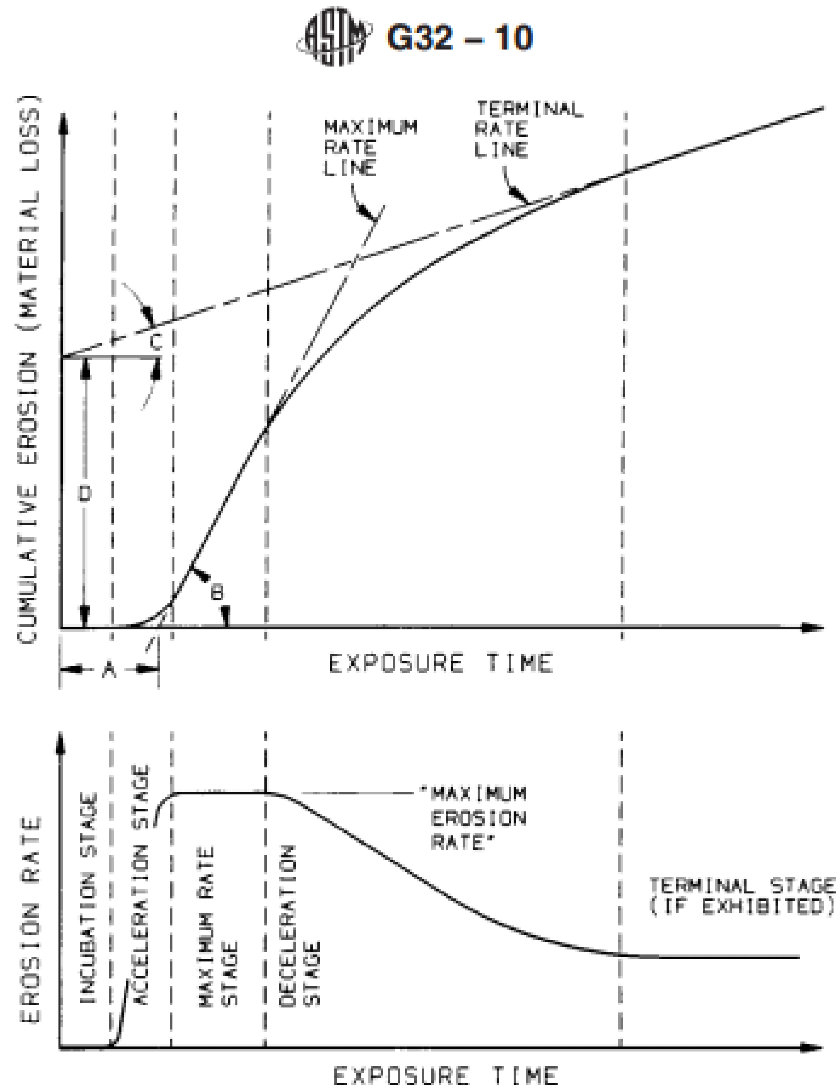


1. Formation of a bubbles on the surface of the material.
2. Collapses of the bubbles that damage the surface.
3. Modification of the surface and its exposure to erosion
4. Formation of new bubbles.
5. Collapses of bubbles eroding the surface even more.
6. Formation of deeper craters.

Standard ASTM G32-2010:

The erosion process undergoes the following stages:

- *Incubation stage*
- *Acceleration stage*
- *Maximum rate stage*
- *Deceleration stage*



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CaviMeter:

Designed by NPL to measure cavitation

Field of Application/Measurement range:

- ***Medical application: 40-60 kHz***
- ***Sonochemical application ≈ 20 kHz***

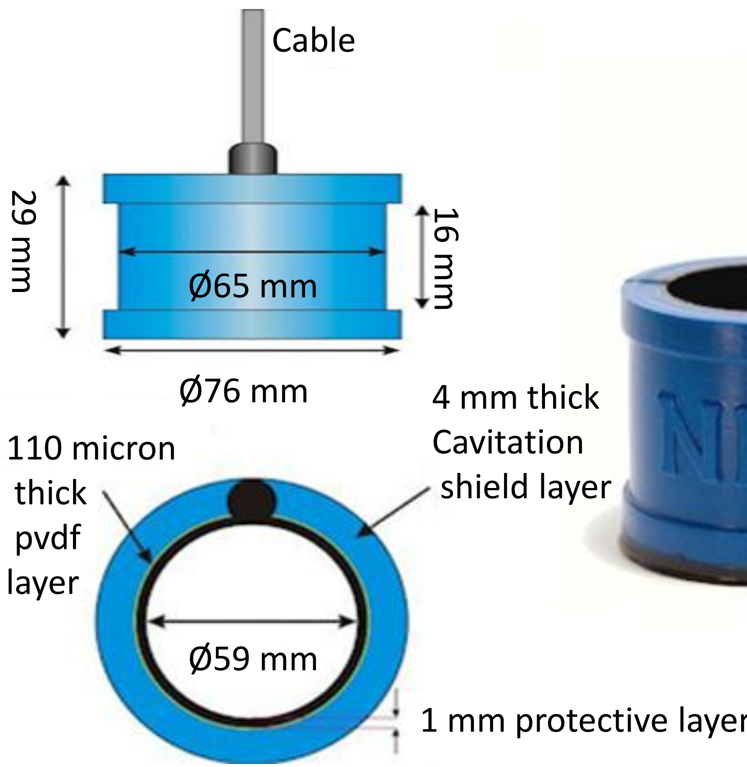
Technical characteristics of the Cavimeter:

Piezoelectric type PVDF, 110 microns, coated with a thick layer of a special rubber (insulator).

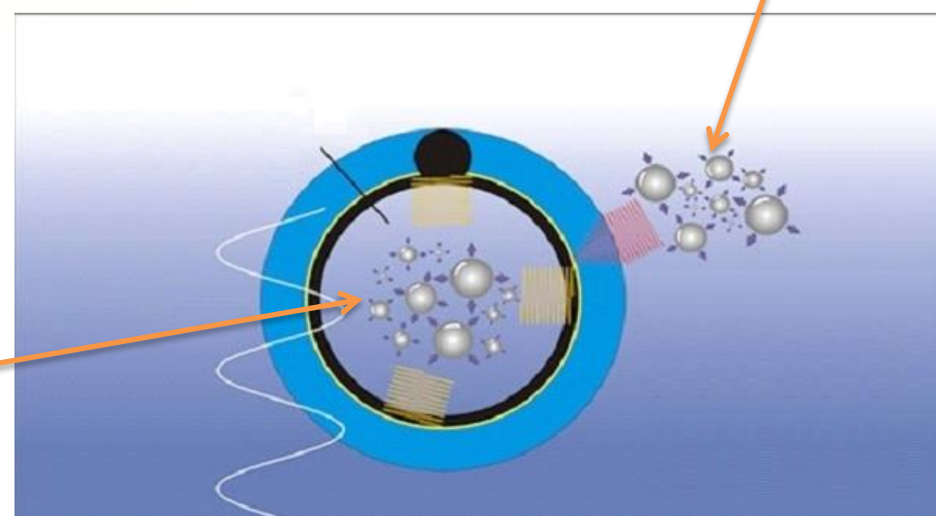
The acoustic field induced by the bubbles is detected by the piezoelectric sensor.

***PVDF**: Polyvinylidene fluoride*

CaviMeter



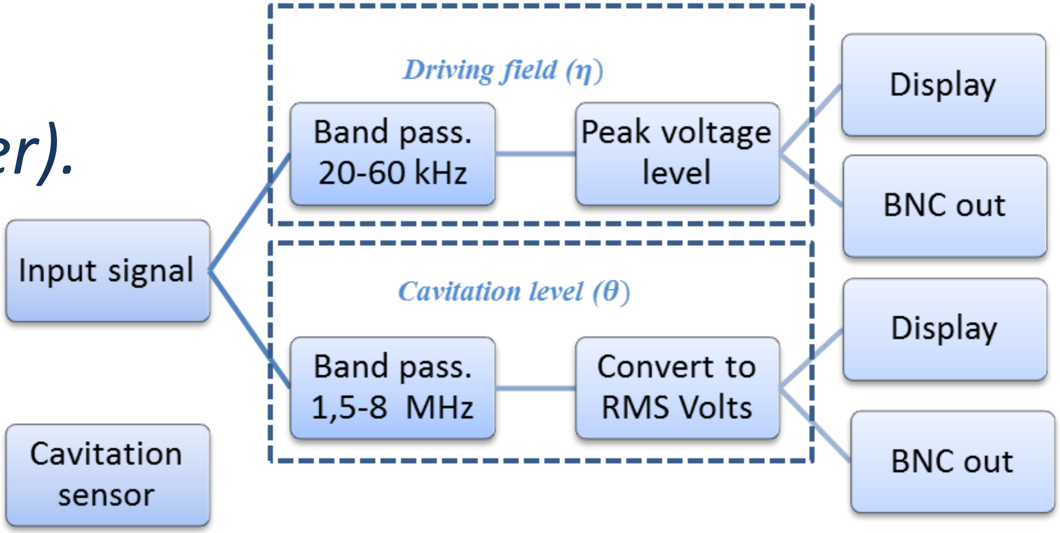
Bubbles outside sensor produce MHZ signals attenuated by sensor outer shield



Cavitating bubbles inside sensor produce MHz signals detectable by PVDF film

Outputs of the CaviMeter:

DRIVING FIELD: *acoustic signal at the fundamental frequency (operating frequency of the transducer).*



CAVITATION LEVEL: *acoustic signal produced by the collapse of the bubbles (takes place in the frequency range 1.5 and 8 MHz).*

Experimental procedure

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Fluid medium (cavitation erosion)

Distilled water (5 micron filtered) at 22±2 °C (Tank: 15 l)

Generation of Cavitation: Ultrasonic transducer, 20 kHz (Model 23820A; Processor P100/3-20).

Duration of Cavitation exposure: 900 to 3600 s

Erosion: assessed by mass loss under a strict protocol

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Operating conditions:

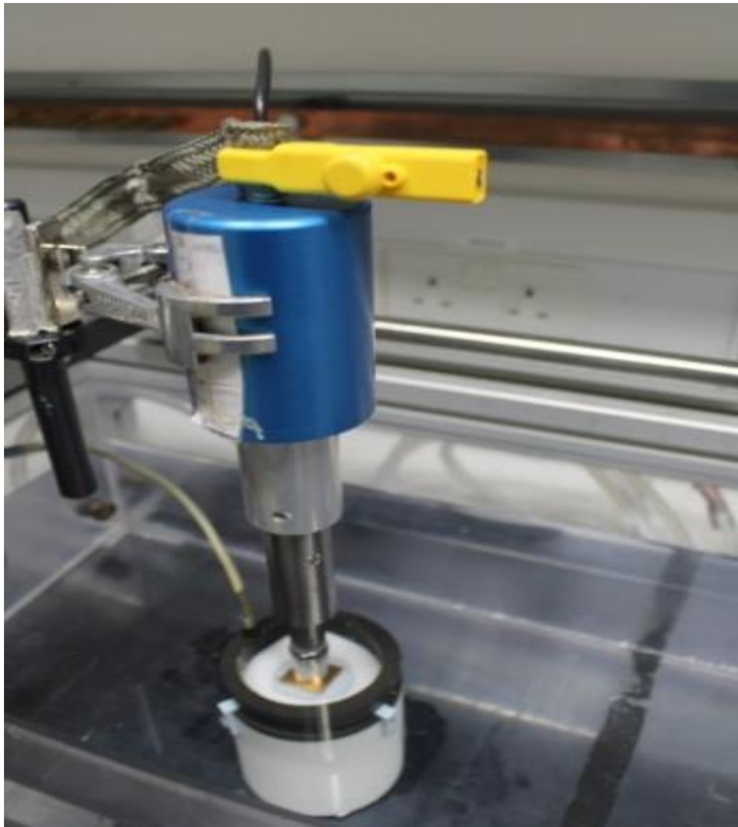
*Experiments operating conditions: conducted for two values of sonotrode-sample **separation (λ)** of the transducer horn with respect to the specimen, at a fixed value of the **transducer displacement amplitude signal (δ)**:*

Experiment #1:

[λ = 0.5mm; δ = 43.5 µm]

Experiment #2:

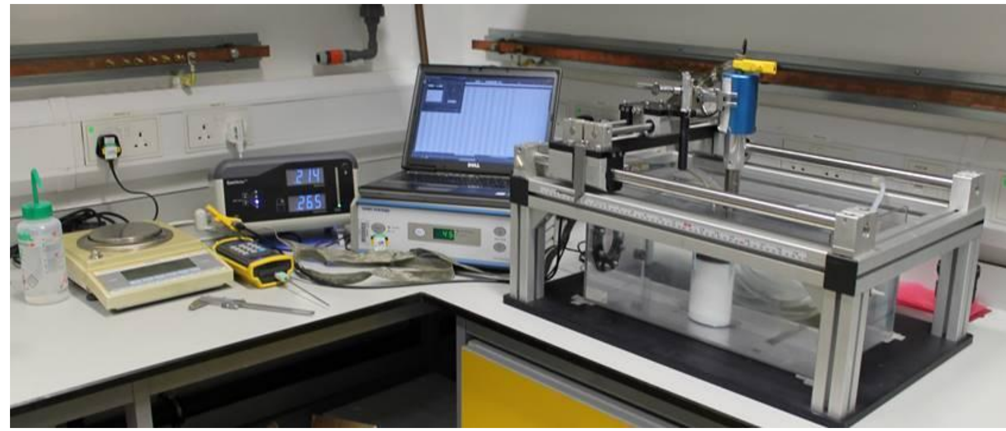
[λ = 1.0mm; δ = 43.5 µm]



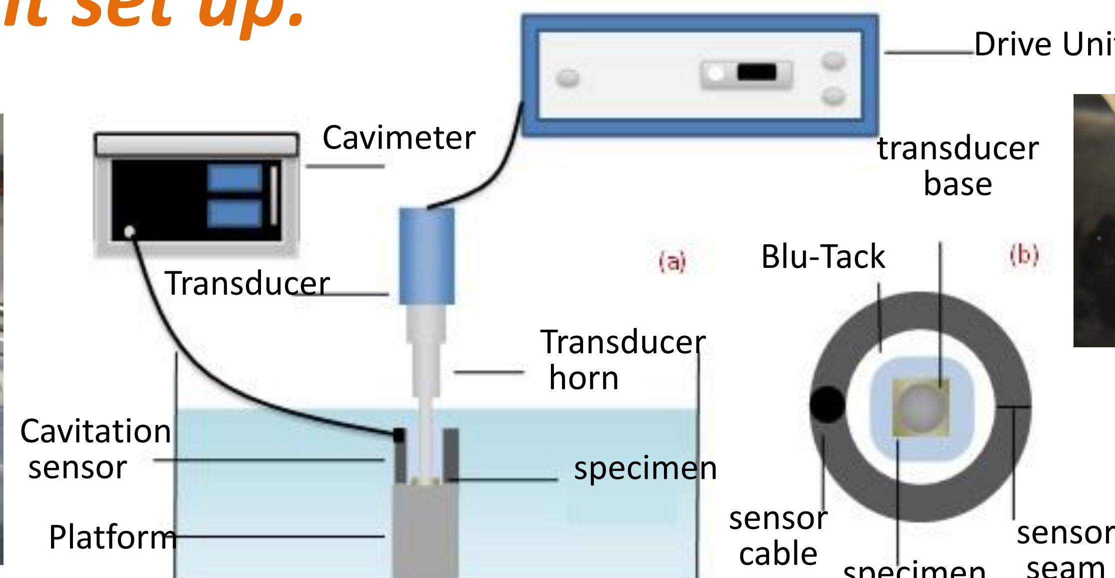
Experimental procedure

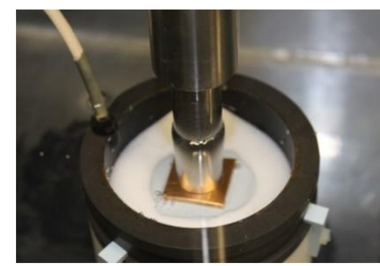
Aluminium-Bronze Alloy investigated under erosion:

Specific mass (mg/mm^3)	Brinell Hardness (HB)	Dimensions (mm)
8.90	170	20 x 20 x 3



Equipment set up:





Analysis of the experimental results

1. Focused on the cavitation phenomenon

Variation associated with measurement of cavitation level

2. Focused on the erosion phenomenon

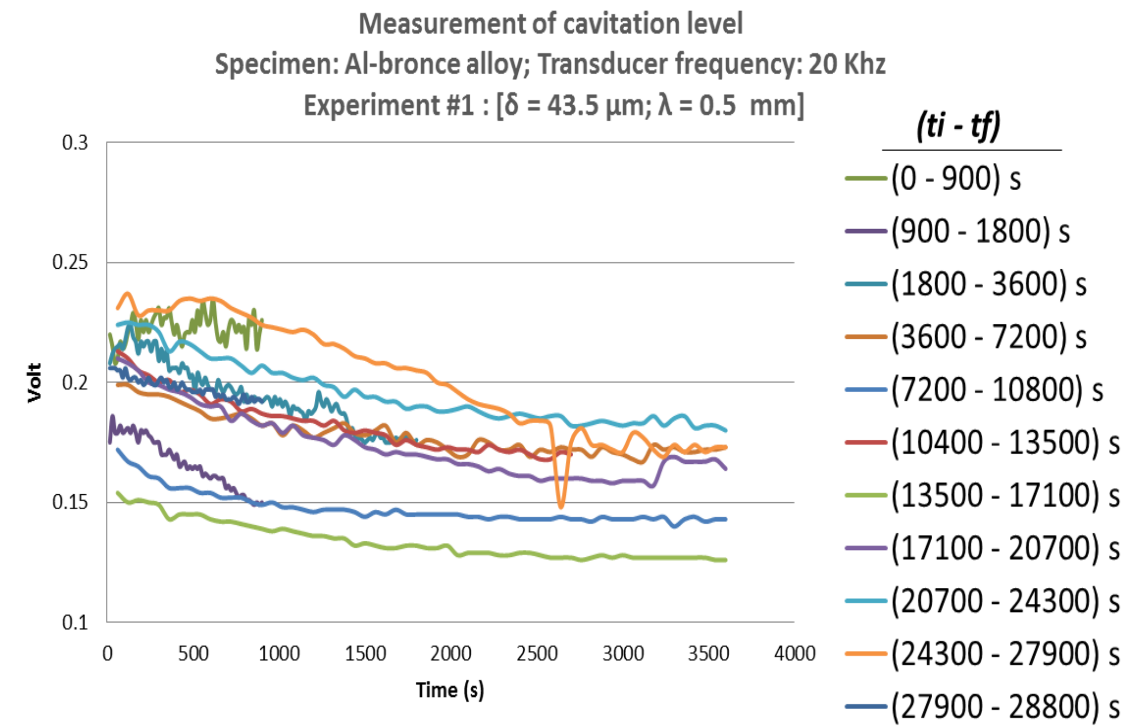
- *Mass loss*
- *Inspection of the specimen surface after erosion*

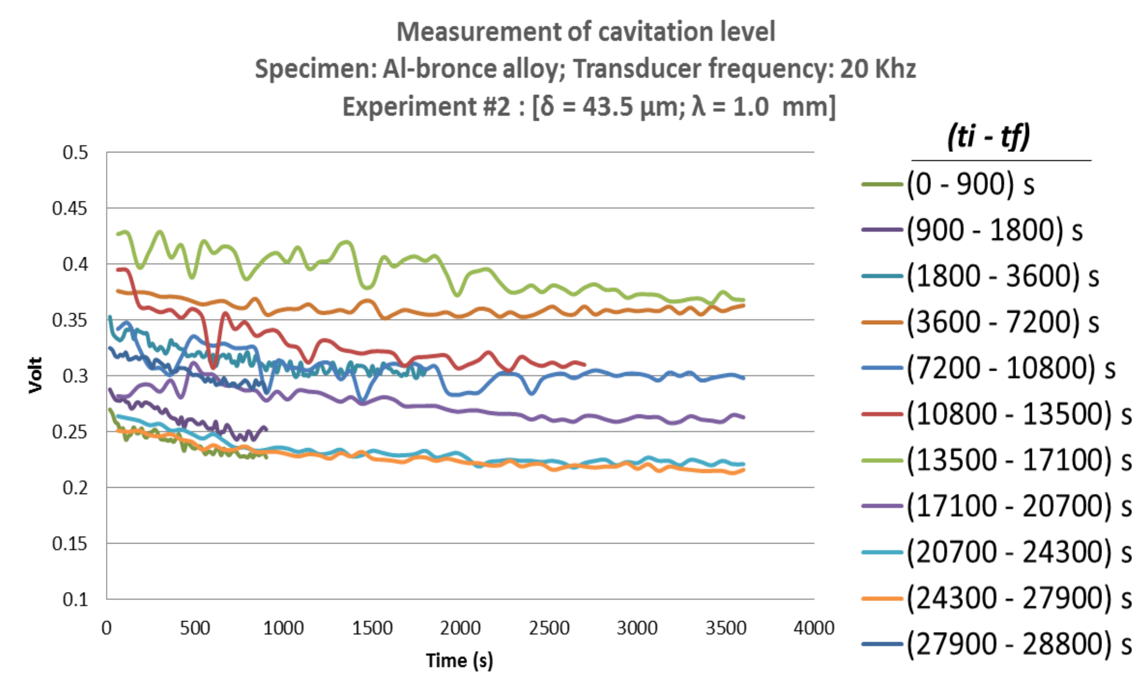
3. Correlating cavitation with erosion resistance

Cavitation level and Erosion rate

Experimental results

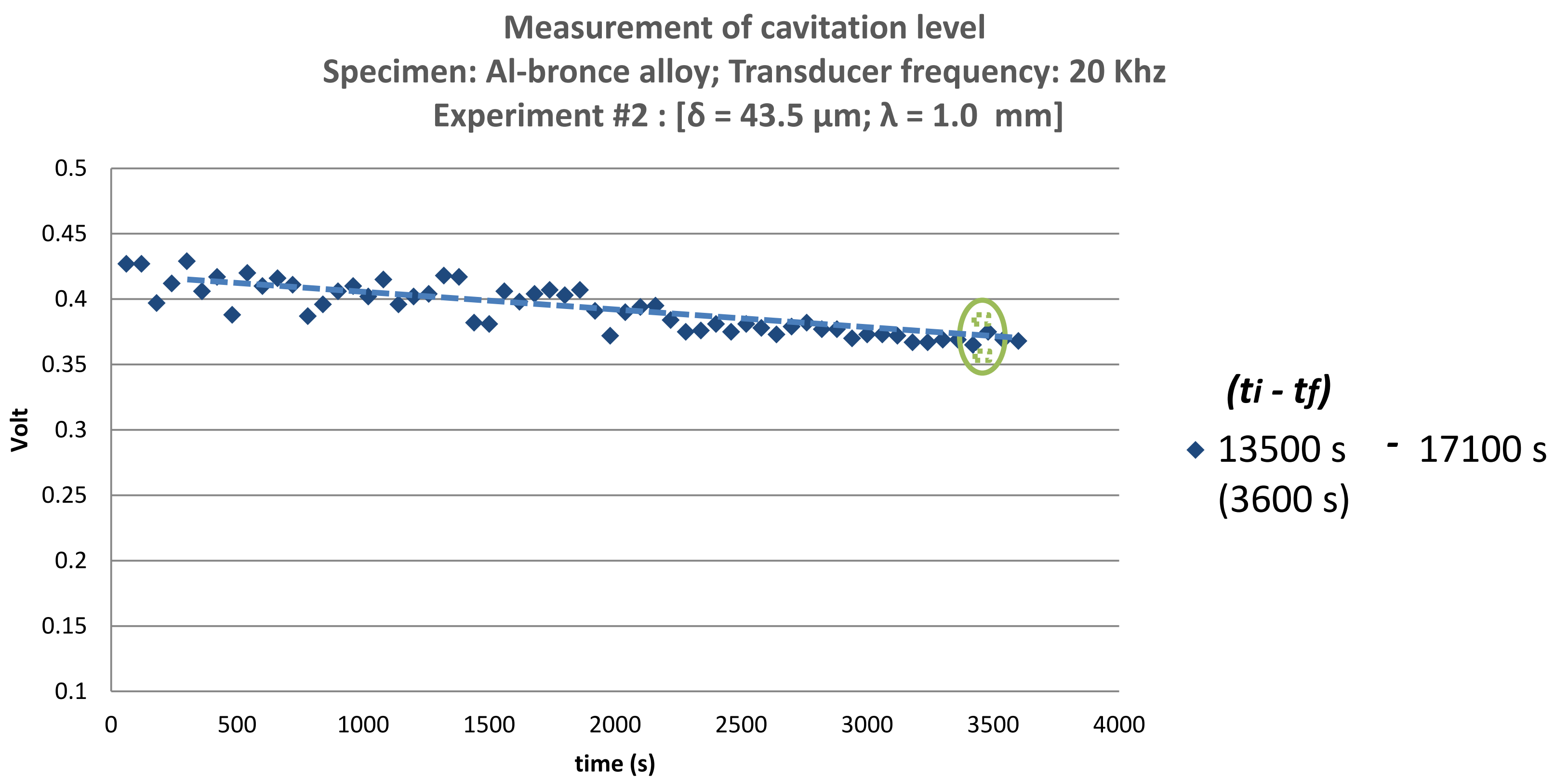
Focused on the cavitation phenomenon





Analysis of the experimental results

Focused on the cavitation phenomenon



Trend: evaluated by the qui-square test

Variation associated with measurement of cavitation level (Estimated uncertainty):
Calculate by the minimum square method

Analysis of the experimental results

Focused on the cavitation phenomenon

					Experiment #1					Experiment #2				
Discrete intervals	t_{in} (s)	t_f (s)	$(t_f - t_{in})$	N_m	Q	χ2	Uniform or non-uniform Pattern?	$\bar{\theta}$ (Volt)	u_s (%)	Q	χ2	Uniform or non-uniform Pattern?	$\bar{\theta}$ (Volt)	u_s (%)
1	0	900	900	60	5.73	11.34	Yes	0.223	2.2	10.83	13.28	Yes	0.240	1.5
2	900	1800	900	60	8.6	15.09	Yes	0.166	1.1	4.4	15.09	Yes	0.262	1.2
3	1800	3600	1800	30	38.33	21.7	No	0.195	1.8	22.22	16.81	No	0.315	1.4
4	3600	7200	3600	60	27.5	16.81	No	0.178	1.2	14.8	15.09	Yes	0.361	0.9
5	7200	10800	3600	60	18.53	11.34	No	0.148	0.7	24.5	13.28	No	0.306	3.3
6	10800	13500	2700	45	9.56	13.28	Yes	0.183	0.8	12.51	11.34	No	0.330	2.6
7	13500	17100	3600	60	24.5	13.28	No	0.134	0.7	6.4	15.09	Yes	0.392	2.4
8	17100	20700	3600	60	9.5	13.28	Yes	0.174	1.1	12.83	13.28	Yes	0.274	1.7
9	20700	24300	3600	60	22.8	15.09	No	0.195	0.8	31.8	15.09	No	0.232	1.1
10	24300	27900	3600	60	3.8	15.09	Yes	0.201	2.4	10.6	15.09	Yes	0.227	0.9
11	27900	28800	900	60	4.17	16.81	Yes	0.198	0.6	15	13.28	No	0.304	0.8
			Total Number of measurements N_m	615										

$$N_m = Number\ of\ measuring\ point$$
$$Q = Statistics\ of\ the\ qui\text{-}square\ test$$
$$X^2 = value\ of\ qui\text{-}square\ table$$
$$If\ X^2 > Q, the\ cavitation\ measuring\ follow\ a\ uniform\ pattern$$

$$u_s = \sqrt{\sum_{i=0}^{N_m} \frac{[y(x_i) - y_i]^2}{N_m - z - 1}};$$ in this equation: (u_s a measure of uncertainty)

$y(x_i) = \theta(t_i)$ = Adjusted value of the cavitation level

$y_i = \theta_i$ = Measured value of the cavitation level

z = Degree of polynomial adjustment ($y(x_i)$)

Analysis of the experimental results

Focused on the cavitation phenomenon

Discrete intervals	t_{in} (s)	t_f (s)	$(t_f - t_{in})$	N_m	Experiment #1 Q	Experiment #1 χ2	Experiment #1 Uniform or non-uniform Pattern?	Experiment #1 $\bar{\theta}$ (Volt)	Experiment #1 u_s (%)	Experiment #2 Q	Experiment #2 χ2	Experiment #2 Uniform or non-uniform Pattern?	Experiment #2 $\bar{\theta}$ (Volt)	Experiment #2 u_s (%)
1	0	900	900	60	5.73	11.34	Yes	0.223	2.2	10.83	13.28	Yes	0.240	1.5
2	900	1800	900	60	8.6	15.09	Yes	0.166	1.1	4.4	15.09	Yes	0.262	1.2
3	1800	3600	1800	30	38.33	21.7	No	0.195	1.8	22.22	16.81	No	0.315	1.4
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11	27900	28800	900	60	4.17	16.81	Yes	0.198	0.6	15	13.28	No	0.304	0.8
			Total Number of measurements N_m	615										

The Chi-square statistical treatment of instantaneous measurements indicates the existence of non-uniform distributions of the cavitation level.

Focused on the cavitation phenomenon

Experiment #1 (λ = 0.5 mm) :

- ***6 of 11 accumulative time interval kept a uniform distribution based on statistical analysis (chi-square test)***
- ***Maximum variation associated with measurement of cavitation level : 0.0049 V***
- ***Cavitation level average : 0.181 V***

Experiment #2 (λ = 1.0 mm) :

- ***6 of 11 accumulative time interval kept a uniform distribution based on statistical analysis (chi-square test)***
- ***Maximum variation associated with measurement of cavitation level : 0.0101 V***
- ***Cavitation level average : 0.295 V***

Change of λ from 0.5 mm to 1.0 mm (δ kept constant):

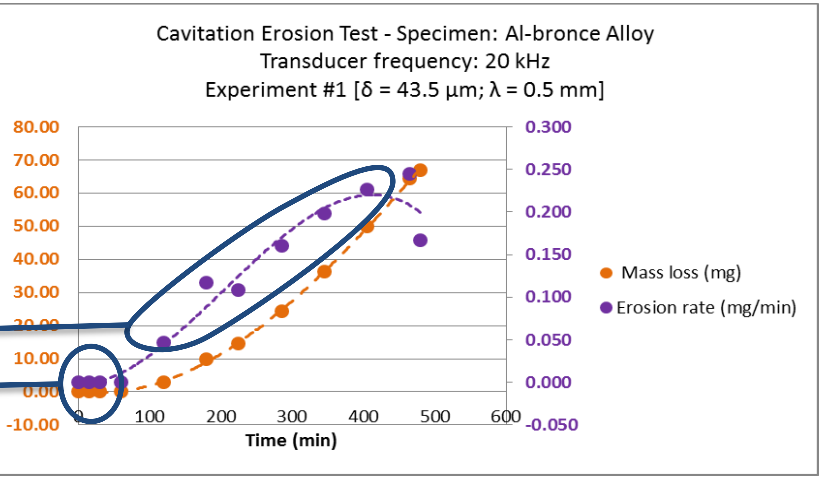
- No significant influence on the distribution of the cavitation Level.
- Maximum variation associated with measurement of cavitation level: increased from 2.7% to 3.4%.
- 62% influence on the cavitation level average.

Analysis of the experimental results

Focused on the erosion phenomenon

Experiment #1
[δ = 43.5 μm; λ = 0.5 mm]

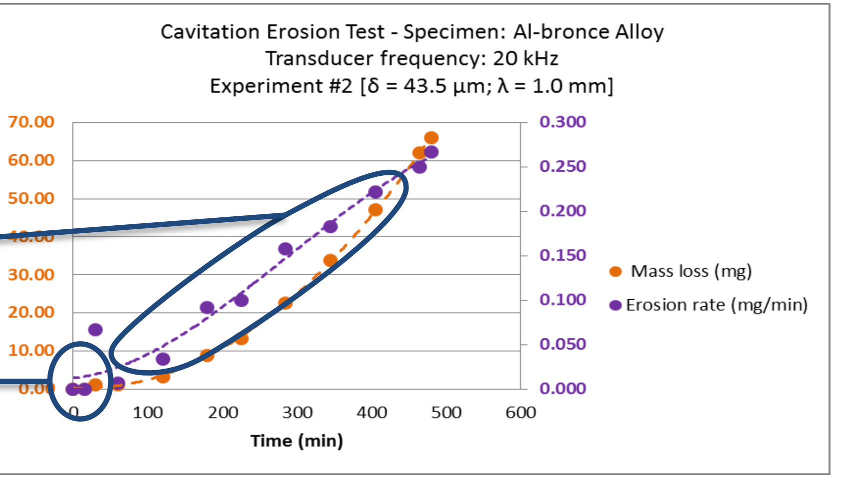
Acceleration stage of erosion
Incubation stage of erosion



Experiment #2
[δ = 43.5 μm; λ = 1.0 mm]

Acceleration stage of erosion

Incubation stage of erosion



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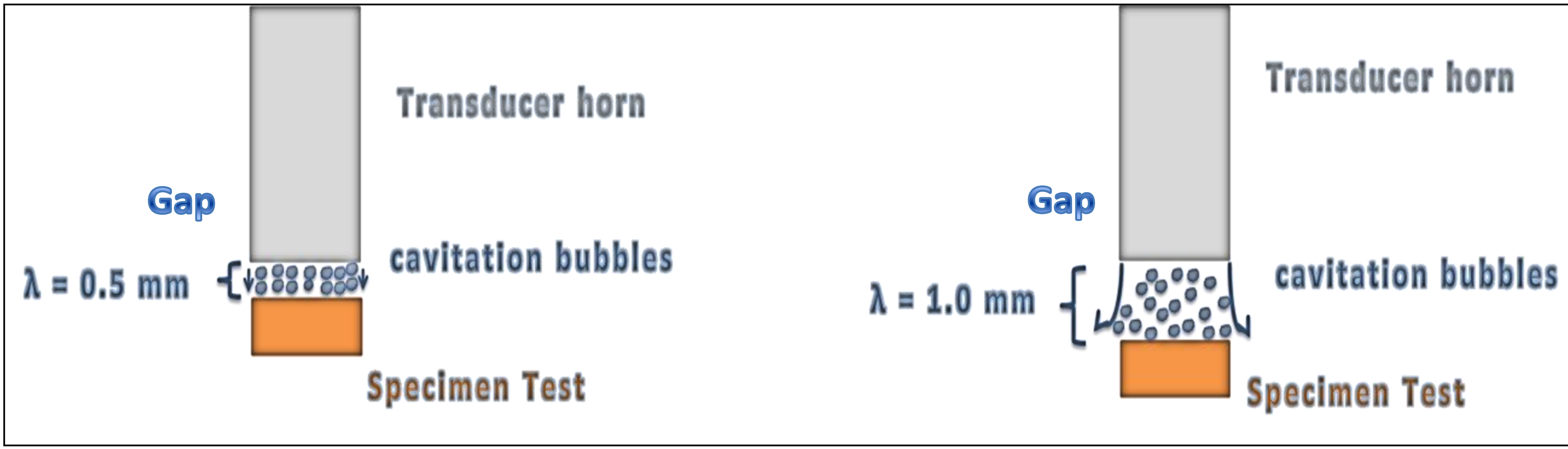
Gap effect



For λ = 0.5 mm, the bubbles are confined within the gap. The bubbles spread to the edges as λ increases.

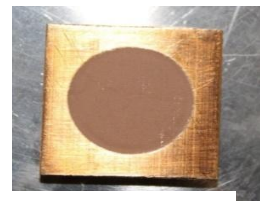
Surface aspect of the aluminum-bronze alloy, before and after exposure to erosion

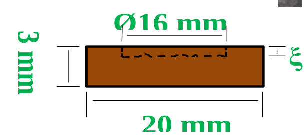
Al-Bronce Alloy

before erosion

After erosion

Condition #1 [δ = 43.5 µm; λ = 0.5 mm]

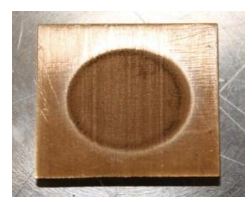


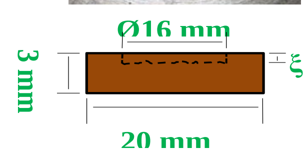


t= 480 min, Δm = 67.0 mg
ξ = 37.44 µm

After erosion

Condition #2 [δ = 43.5 µm; λ = 1.0 mm]

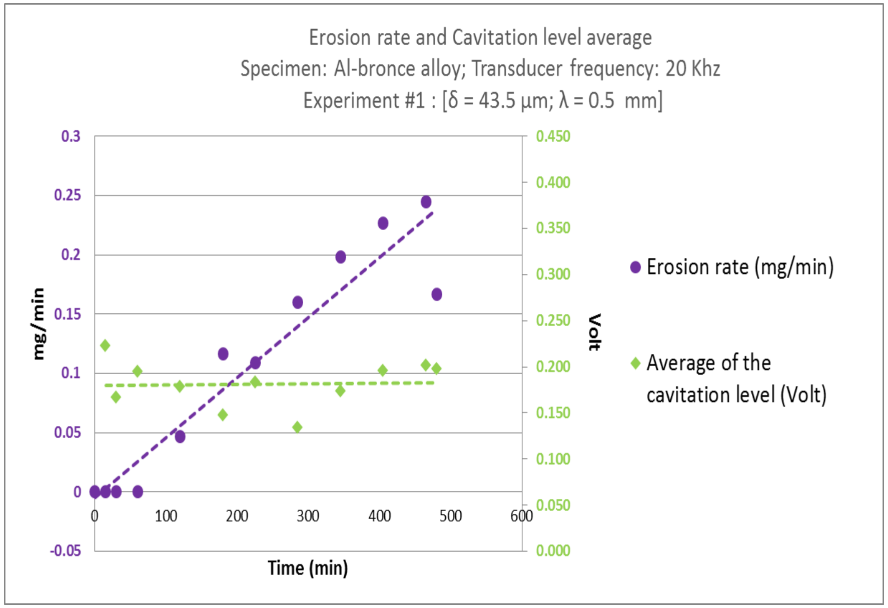


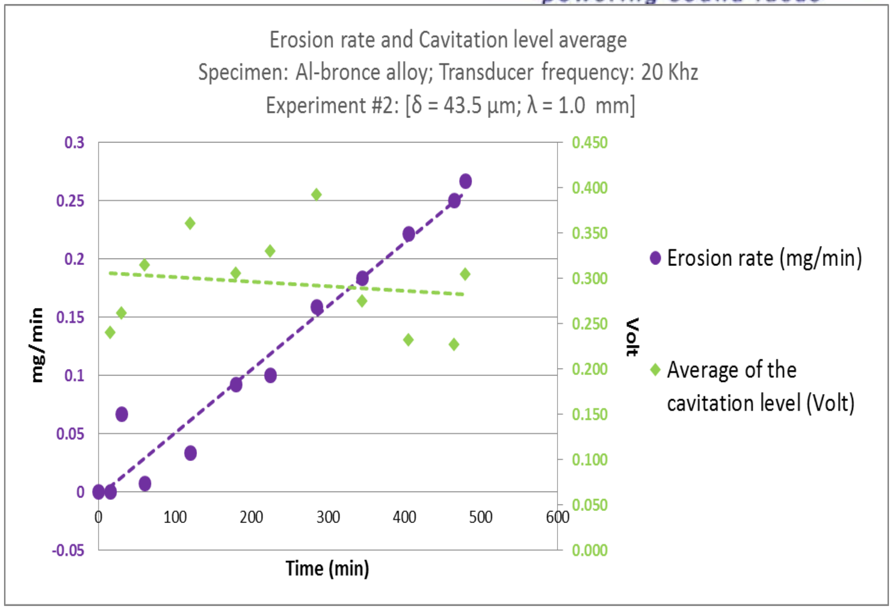


t= 480 min, Δm = 66.0 mg
ξ = 36.38 µm

Analysis of the experimental results

3. Correlating cavitation with erosion resistance





$\bar{\theta}_{\lambda=0.5\,mm} < \bar{\theta}_{\lambda=1.0\,mm}$ (more bubbles emitting in between the gap in $\lambda = 1.0\,mm$)

$\bar{\theta}$ = Cavitation level average

λ = Sonotrode-sample separation

***eroded surface may not affect the cavitation level average (new experiments with others materials are been doing to verify this)**

Conclusions

- *The experimental apparatus allowed the* **evaluation of cavitation during erosion tests** *performed with aluminum-bronze alloy.*
- *The study illustrated (quantitatively) the* **influence induced by the λ parameter**. *The results of the experiments showed that variation of λ (λ = 0.5 mm and λ = 1.0 mm) impacts 1.5 % on the mass loss of aluminum-bronze alloy.*
- *Results confirmed that over a similar timescale, the higher the erosion rate the higher the mass loss.*
- *Even though the study may suggest that the* ***presence of the eroded*** *specimen in the* ***cavitation field*** *may be held responsible for non-uniform distributions of the cavitation level, further experiments involving other engineering materials offering different resistance to erosion might be welcome to correlating inertial acoustic cavitation emissions with material erosion resistance.*

Next steps

Automation of the experiments

To reduce associated errors and to improve data acquisition procedure.

Implementation of new operation conditions

By increasing transducer amplitude (δ) and displacement (λ) of the transducer horn wrt specimen.

Implementation of new experiments

To express measurement results of cavitation ***in terms of the basic principle*** *associated with the phenomenon of cavitation.*

Main References

[1] CHOI, J.; JAYAPRAKASH, A.; CHAHINE, G. Scaling of cavitation erosion progression with cavitation intensity and cavitation source. Wear, v. 278, p. 53-61, MAR 8 2012 2012. ISSN 0043-1648

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Thank you!