IOSUD –Timisoara Polytechnic University
Doctoral School for Engineering

THE FLOW BY THE BUTTERFLY VALVES AND THE CAVITATION EROSION TO COMPONENTS BY AUSTENITIC STAINLES STEELS

Doctoral degree thesis – Summary

Doctoral field: Mechanical engineering

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1. THE CURRENT STATE OF RESEARCH

Butterfly valves receive their names from the movement of the disc which rotates for closing or opening a hydraulic circuit or controlling his flow capacity. The disc (named frequently valve) rotation is possible in a vertical or horizontal plan, manually,electrically, hydraulically or pneumatically. The driving mode depends on the pipe inner diameter and the pressure range.

The using range of such devices is very large. There are found in hydraulic facilities fig.1.1, pump stations, petrochemical industry etc. [1, 4, 10, 12, 13, 14, 36, 38, 47, 73, 90, 96, 127, 141, 155].

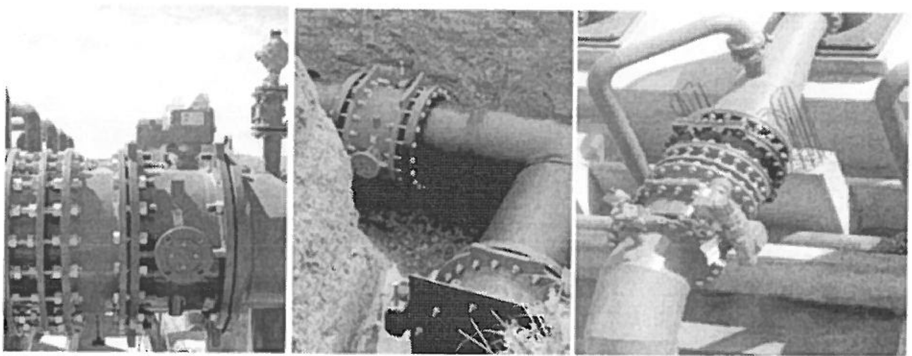


Fig.1.1 Butterfly valve mounting solutions on water supply lines.

Table 1 presents some Romanian Hydroelectric Power Plants endowted with butterfly valves, mosst of them beeing designed and mounted by SC HydroEngineering SA.

Tabele 1.1 Butterfly valves in Romanian Hydroelectric Power Plants

Employer (HPP)	Nominal Diameter (mm)	Computing Head (m)	Position in the hydraulic circuit
Voineasa	350	160	Turbine input
Stejaru	500	160	Turbine input
Teliuc	600	400	Turbine input
Tarniţa	800	100	Turbine input
Cugir	450	100	Turbine input
Râul Alb	2400	110	Pressure junctiom
Godeanu 2	500	160	Turbine input
Motru	2800	150	Pressure junctiom
Herculane	1200	100	Turbine input

A special group is represented by the vanes with twin disks used in Romania for pipes with large dimensions. Some of them are presented below:

- Hydroelectric Power Plant „Râul Mare Retezat" (nominal diameter =3600 mm, nominal pressure = 175 m water column),
- HPP "Mărişelu" (nominal diameter = 3200 mm, nominal pressure= 100 mwc),
- HPP„Dâmboviţa – Clăbucet" (nominal diameter = 2800 mm, nominal pressure = 120 mwc,
- HPP„Colibiţa" (nominal diameter = 2000 mm, nominal pressure = 110 mwc),
- HPP„Răstoliţa" (nominal diameter = 2300 mm, nominal pressure = 125 mwc).
- HPP„Ruieni" (nominal diameter = 3600 mm, nominal pressure = 140 mwc),

From the working point of view, the valve is special hydro-mechanical equipment used forcontrolling the flow capacity till the desired level or even to stopcompletely the flow downstream.They are important components for hydroelectric power plants, pumping stations, water storage dams or deviation dams. Regardless of the constructive shape and the closing type, the valves must fulfil some conditions: mechanical resistance corresponding to the maximum occurring pressure, compatibility with the running fluid (chemical composition, pressure, and velocity), minimum hydraulic resistance in the completely openposition, and perfect tightness in the completely position, reliability and safety of operation.

Fig.1.2 (1.3)present the section of a AVK butterfly valve, with plane disk, double eccentric, hand driven, destined for nominal diameters between 200…2200 mm, with water velocity limitations, in conformity with DIN EN 1074, at 2.5 m/s for the nominal pressure of 6 bars and 5 m/s for a nominal pressure for a nominal pressure of 25 bars.The valve can be used closed or with different opening position butto avoid cavitation is recommended the use of openings over 30°.

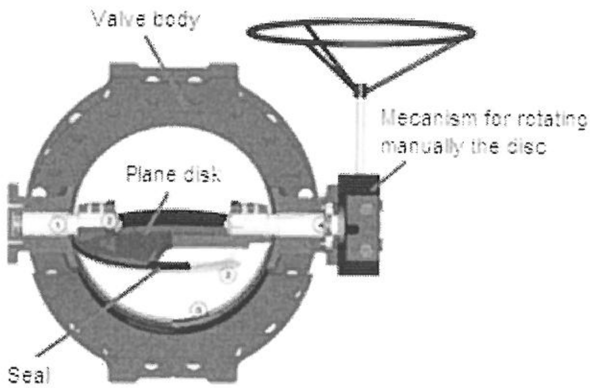


Fig.1.2 (1.3) Butterfly valve with plane valve of AVK type

The specialty literature is poor in results regarding the cavitation in butterfly valves. Anyway, it is sure that the cavitation depend on the flow capacity (through velocity) and the angular position of the valve. Some experimental results presented in Fig. 1.3 (1.12) show that regardless of the disk shape, for opening angles bigger than 50° the valve is running in strong developed cavitation.

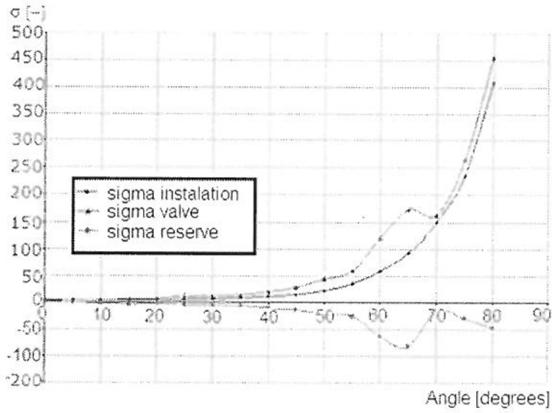


Fig.1.3 (1.12) Cavitation coefficients against opening angle

Observations during repair works on a butterfly valve, after two years running at the pressure of 1,2-1.4 bar, a velocity of 2,2 m/s and a valve opening of approximately 30° fig. 1.4 (1.14), show eroded zones on the ring for fixing thegasket and on the valve seat.

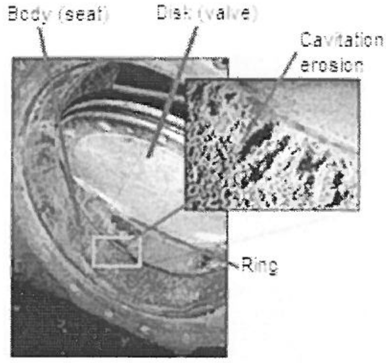


Fig.1.4 (1.14) Butterfly valve eroded through cavitation

From the presented researches the following conclusions can be draw:
1. The researches and the numeric simulations obtained till now, regarding the flowing regimes, confirm that for some angles of the disc and for a given flow capacity there are fulfilled the hydrodynamic conditions for inception and development of the cavitation phenomena.
2. To reduce the erosions of zones subjected to cavitation those are manufactured from stainless steels. The most affected are the sealing zones: the seats, the seals fixing rings, and those fixing the seats.
3. The economic requirements demand the minimization of the detail degradations by applying either coatings and/or various treatments (mechanical, thermal, thermochemical) which can assure a high resistance to cavitation erosions.

The objectives of the PhD thesis are:

- Numerical analyses of the flow in butterfly valves with biplane discs for putting into evidence of the functioning regimes with cavitation and the areas affected by erosion.
- Deepening on the studies of cavitation erosion mechanism produced by the T2 vibratory standard device, with piezoelectric crystals, in the endowment of TPU Cavitation Laboratory (vibration amplitude 50 μm, frequency20000 ±1% Hz, specimen diameter 15.8 mm) there will be found technological modification for increasing the resistance to erosion of the austenitic stainless steel X5CrNi18-10,especially through volumic heat treatments(quenching for puting into solution at constant temperature and various maintenance durations reapective different heating temperatures at constant maintenance durations) as well as superficial treatments (nitration in gaseous environment and laser beam).
- Morphology and caracterization of the microstructure for the areas subjected to cavitation.
- A new concept for the hierarchisation of the stainless steels in concordance with the cavitation erosion resistance

Phd thesis contributions :

The new contributions of the PhD thesis consists in the identification of the operating regimes of butterfly valves with biplane disc at which cavitation flow occur. This result was obtained through numerical simulation. In order to increase the cavitation erosion resistance of austenitic stainless steel X5CrNi18-10 (frequently used for realizing butterfly valves) there were analyzed various heat treatments and superficial coverings.The best results were obtained for superficial treatments with laser beams (with 240W) and gas nitration.For volume treatments the best results were obtained for quenching with heating at 1050 °C with 25 minutes of maintenance and cooling in water.

2. RESEARCED MATERIAL. EXPERIMENTAL PROCEDURE

The prescribed [165]as well as the effective chemical composition of the austenitic stainless steel is presented in Table 2.1. The principal mechanical characteristics determined in Timisoara Polytechnic Laboratories are: R_m = 550 MPa, $R_{p0.2}$= 195 MPa, Brinell hardness HB = 183 daN/mm^2 (approximately HV = 192 daN/mm^2), elongation at break A_5 = 45 %.

Table 2.1 Chemical composition of the researched steel X5CrNi18-10

Component chemical elements [%]										
C	Cr	Ni	Mn	Si	Cu	W	P	S	N	Fe
Prescribed [20]										
0.07	17.5-19.5	8.0-10.5	2.0	1.0	-	-	0.045	0.015	≤0.11	rest
Measured in UPT Laboratories										
0.046	17.95	8.11	1.46	0.89	0.27	0.16	0.024	0.019	indefinite	rest

In conformity with the Schäfflerdiagram fig.2.1(2.5), the microstructure of this steel, as delivered, is formed from about 88 % austenite and 12 % δferrite.

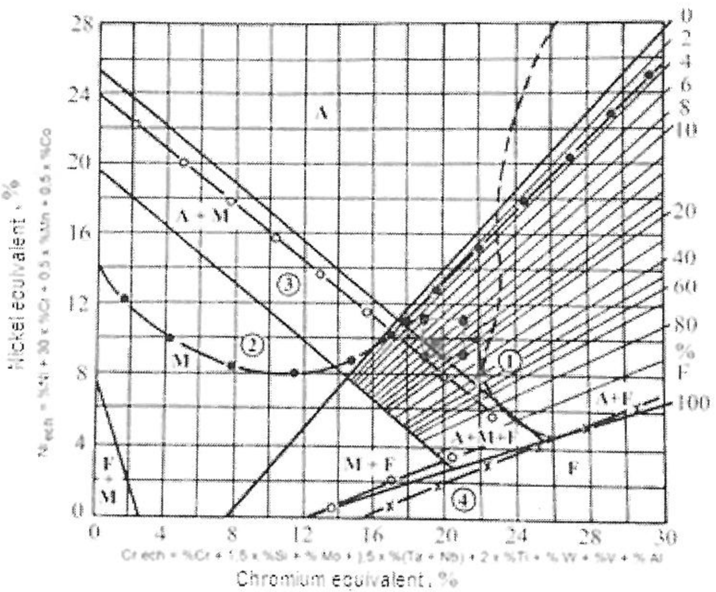


Fig.2.1 (2.5) Positioning of the researched steel in the Schäfflerdiagram

In fig.2.2 (2.7) is given the photograph of thevibratory devices with piezoelectric crystalsfound in Timisoara Polytechnic University Laboratory. In the same figure is presented also a cross section through the specimen used for cavitation erosion tests with the main dimensions.

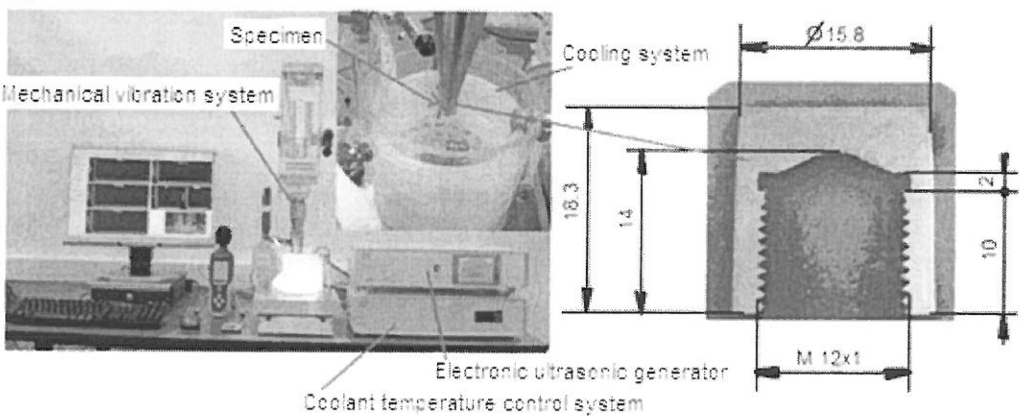


Fig.2.2 (2.7) The standard vibratory device with piezoelectric crystals

The testing method used in TPU Cavitation Laboratory consist in a sequence of steeps after the specimen receives the final form through mechanical processing and heat treatments. The working liquidis brought to the test temperature and the frequency of the vibrations is adjusted to the desired level.

The Timisoara Polytechnic University Laboratories for Cavitation as well as those for Material Engineering have high resolution cameras, high performance optic and electronic microscopes for the micro and macroscopic investigations of the damages produced on the areas exposed to cavitation erosion. For this purpose have been used also devices for the surface preparation and metallographic analyzes.

The steels with preponderant austenitic structure, received through refining chemical elements and adequate treatments, have the capacity to modify their structure and mechanical properties for assuring the increase of cavitation erosion resistance. The austenitic stainless steel X5CrNi18-10 investigated in this PhD thesis, is a material suitable to the thermochemical and volume heath treatments established by the objectives presented in chapter 1, with the purpose to be used for the details subjected to cavitation erosion especially the chair retaining rings of the butterfly valves as well as their axes.

The vibratory device with piezoelectric crystals in the endowment of TPU Cavitation Laboratory used for the experimental tests, respects all the recommendations of the ASTM G32-2010, has exceptional performances and offer high guarantees for the accuracy research results.

The microscopic analyzes equipment found in the endowment of TPU Laboratory for Material Engineering and used for structural examinations offer results of very high accuracy and contributes essentially to the performance of the research results.

3. CAVITATIONAL FLOW ANALYSIS THROUG BUTTERFLY VALVES WITH DOUBLE ECCENTRIC DISCS

In this chapter the modeling of the flow in the valve is realized with the program SolidWorks Flow Simulation and has as purpose the precise determination of the zones affected by cavitation and the establishment of the details which must be protected against erosion by the use of the austenitic steelX5CrNi18-10. The program estimates the expanding of the cavitation phenomenon and the influence upon the performances but take not into consideration some specific phenomena such as: the generation of the cavitation bubbles, their increase and collapse which have great influence upon the cavitation erosion but do have interference upon the valve performances, considered without major geometric alterations. The numeric simulation was realized for 17 positions of the disc between 0° ÷ 80°, with a step of 5 degrees, positions defined from the angle of the plane ZX.

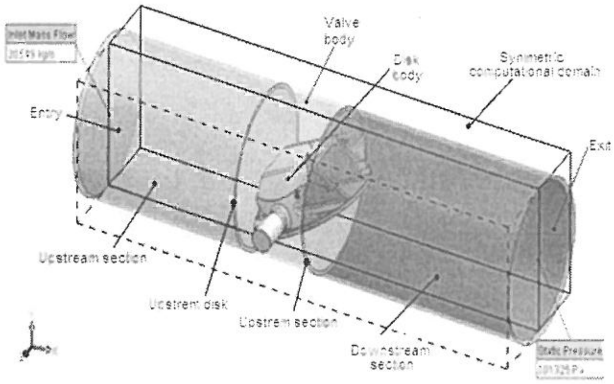


Fig.3.1 (3.3) The computation domain (the analyzed one)

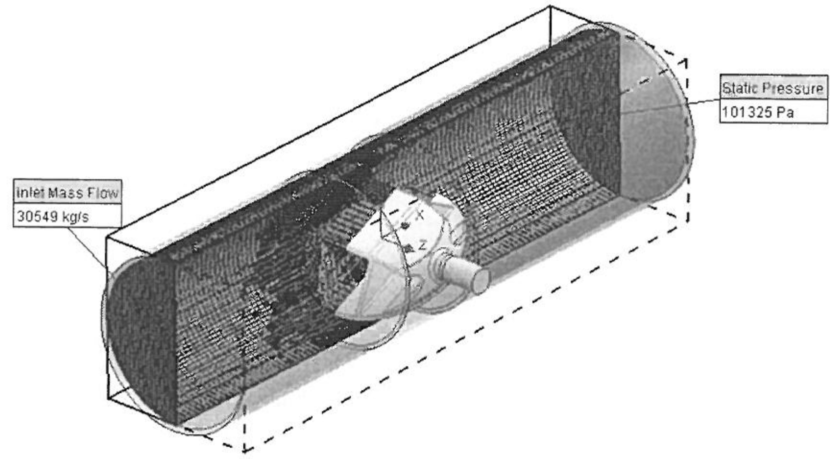
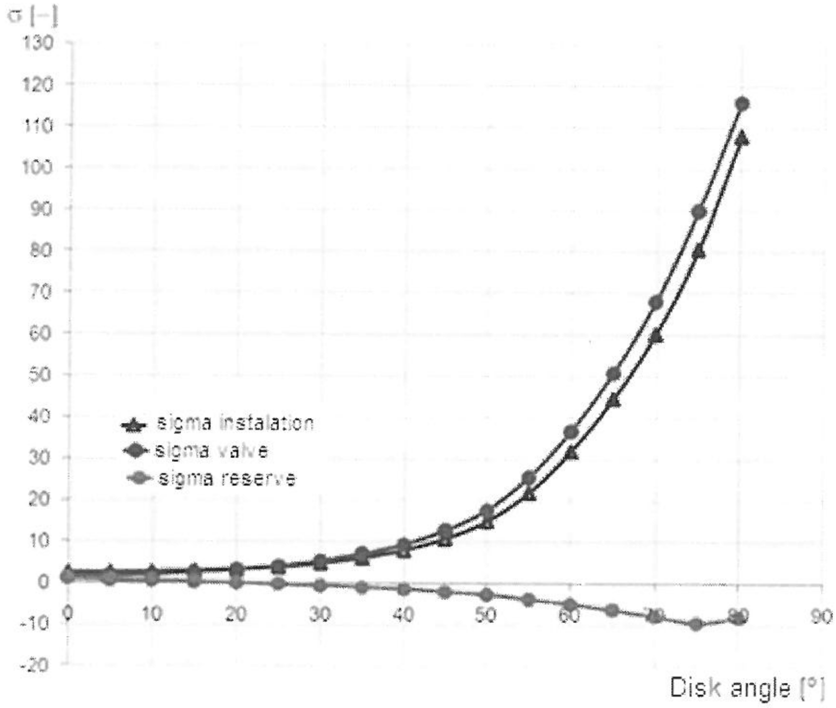


Fig.3.2 (3.4) Discretization of the computation domain



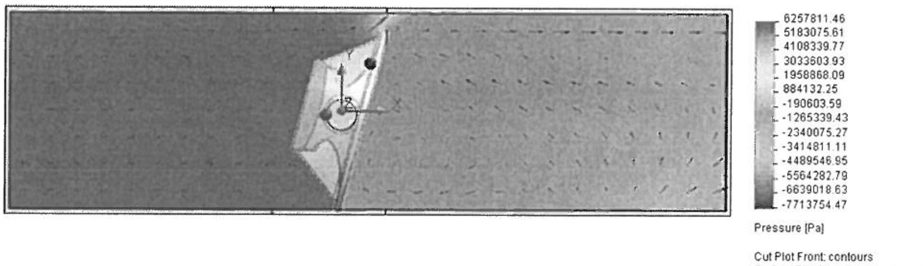


Fig.3.3 (3.83)Pressure distribution for the valve position at75° and Q_{max}=84.18 m^3/s

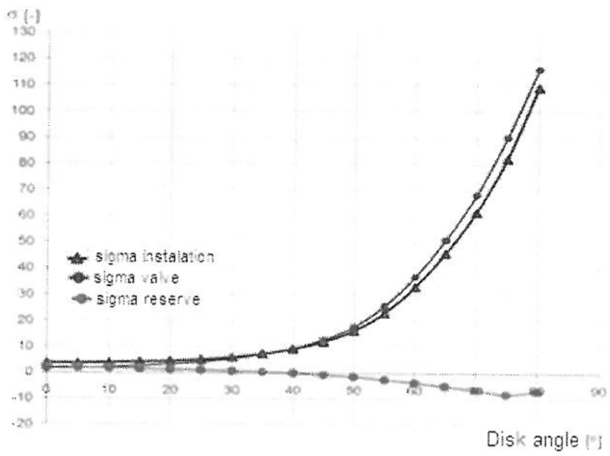


Fig.3.4(3.13) Cavitation coefficients against disc opening angle (Q_n=61 m^3/s)

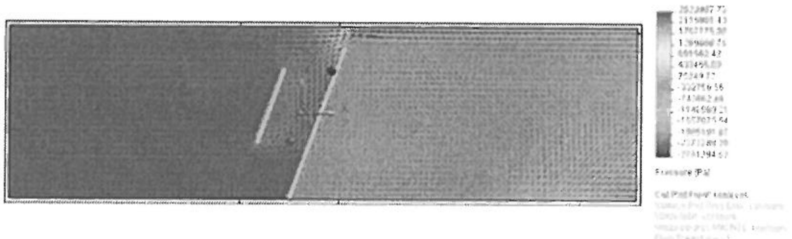


Fig.3.5 (3.28)Pressure distribution for the disc angle 70° and Q_n=61m^3/s

- The modeling results show that butterfly valves with biplane disc have work schemes with cavitation regimes of different intensities. Because the most exposed surfaces are seats, seals retaining rings and retaining seats, for the increase of the running time there are required studies of methods forconfining to the disc the greatest possible resistance to cavitation erosion.
- The realized investigation show that the butterfly valve with biplane disc is transited by cavitation flows with the intensity dependent on the discharge and the opening angle (for a discharge of 61 m^3/s for an disc opening > 45°, and for a discharge of 84,18 m^3/s for an opening >30°).

4. THE INFLUENCE OF VOLUMICHEATH TREATMENTS UPON CAVITATION EROSION RESISTANCE

The experimental researches were obtained using the stainless steel X5CrNi18-10, subjected to quenching for putting into solution.

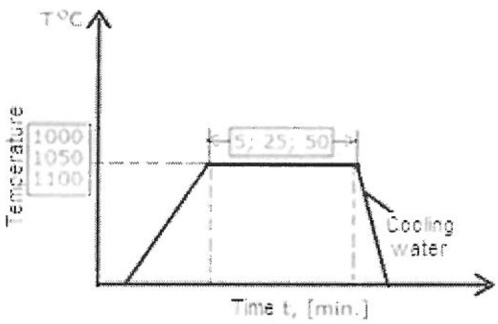
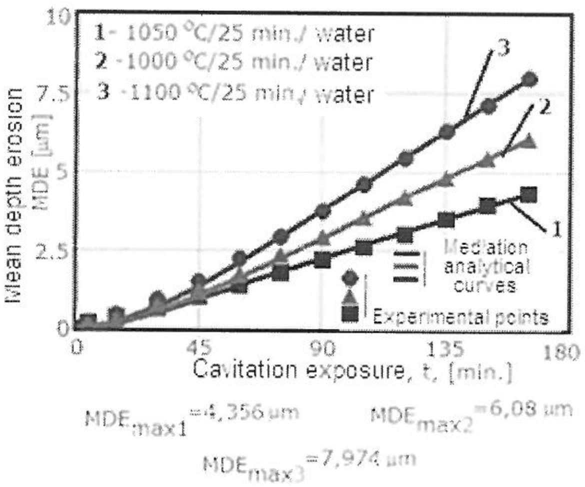


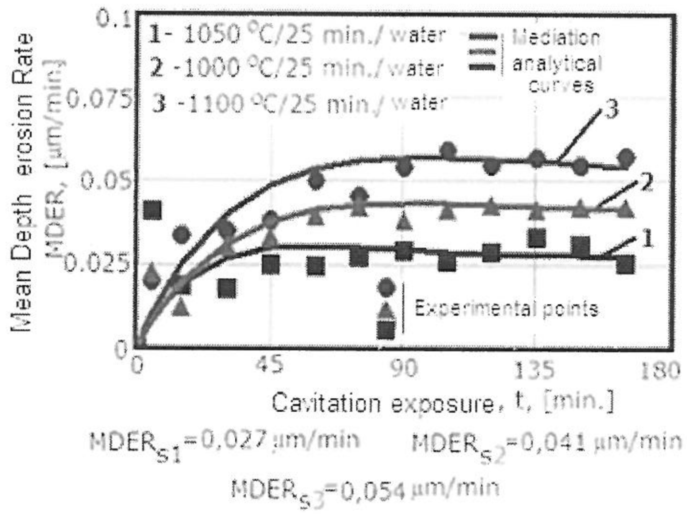
Fig 4.1 Heat treatment diagram

The cavitation erosion experimental researches have been realized with the T2 standard vibratory device, realized inconformity withASTM G32-2010 Standard, respecting the recommendations of the same standard and the customs of the UPT Cavitation Laboratory (with regard to total duration of cavitation erosion exposure 165 minutes divided in two initial periods of 5 and 10 minutes, afterwards a 15 minutes period remain constant till 165 minutes), as well as the methods for preparation and storage of the specimens[114,158]. For each applied treatment were tested three probes. The points in the diagrams are mediations of those three experimentally obtained values.

In fig.4.2 (4.6) are compared the cavitation erosion characteristic curves for the mean depth erosion (MDE) or mean depth erosion rate (MDER) against the exposure duration for heat treatment with different values of the temperature but the same duration of the maintenance at the respective temperature and the cooling agent.



a)



b)

Fig.4.2 (4.6) Cavitation erosion characteristic curves

a) Mean depth erosion against time exposure

b) Mean depth erosion rate against time

Both the shape of the characteristic curves and the scatter of the points are very similar for the three different specimens. It can said that for all three heat treatments there were obtained good cavitation erosion results (through the linearity of the MDE curves after 45 minutes of exposure and the constant values of the MDER curves).The best results was obtained for the quenching procedure 1050 °C/25 min/water. After the value of which MDER curve became approximately constant, the heat treatment at 1050 °C give a cavitation erosion resistance double with regard those with 1100 °C and 1.5 greater than that for 1000 °C.

The material losses, respective the caverns produced by the cavitation phenomena can be explained through the ductile fractureat all the three regimes in which the austenite was produced, fig.4.3-4.5 (fig.4.7-4.9).

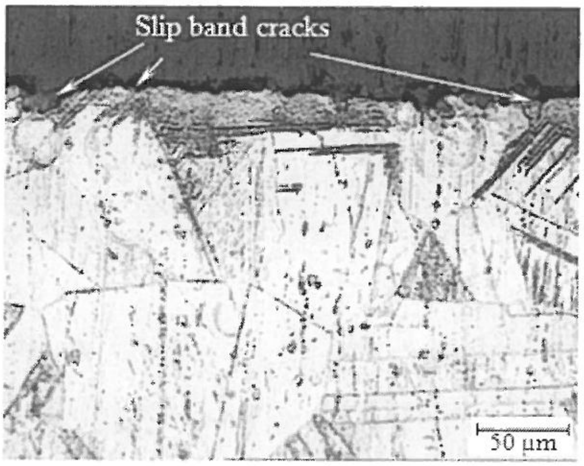


Fig.4.3 (4.7) Microscopic image of the cavitation erosion in transversal section (x 200; Quenching 1000 °C/25 min/water)

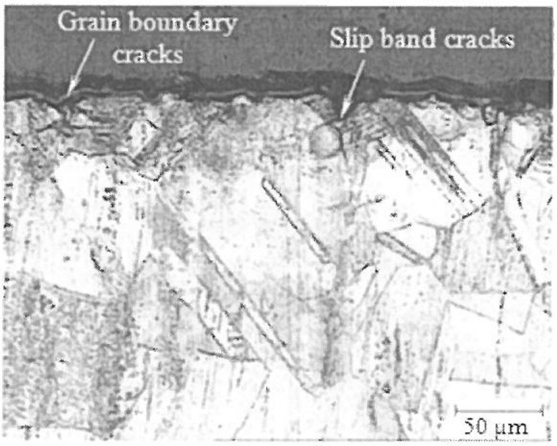


Fig.4.4 (4.8) Microscopic image of the cavitation erosion in transversal section (x200; Quenching 1050 °C/25 min/water)

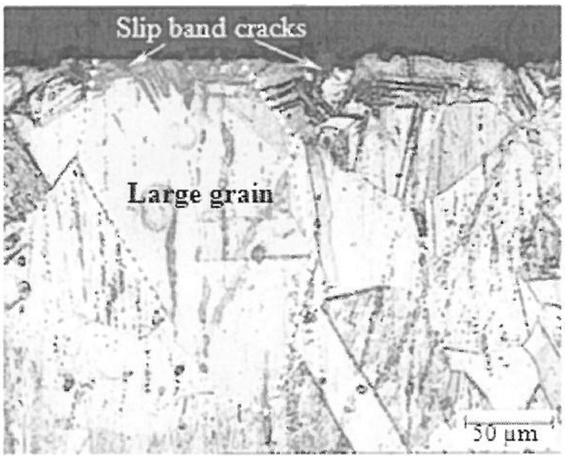
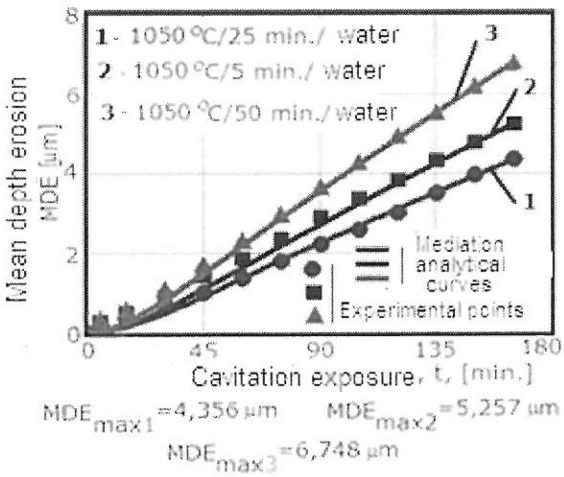
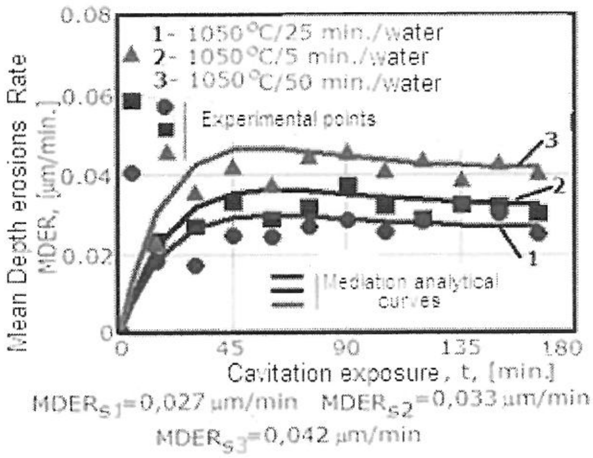


Fig.4.5(4.9) Microscopic image of the cavitation erosion in transversal section (x200; Quenching 1100 °C/25 min/water)

In fig.4.6a,(4.17a,b) are given the cavitation erosion experimental results for volume quenching at the same temperature but different maintaining times.



a)



b)

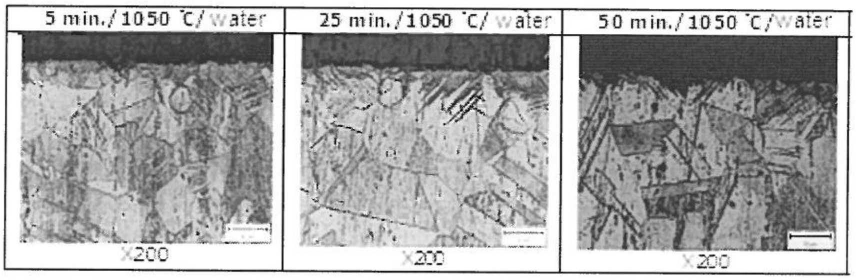
Fig.4.6 (4.17) Cavitation erosion characteristic curves

a) Mean depth erosion against time exposure
b) Mean depth erosion rate against time

It is also evident that regardless of characteristic adopted, the difference between the curves MDE (t), fig.4.6a (4.17a) and MDER (t), fig.4.6b (4.17b), cooled in water for 5 or 25 minutes is very small.

The images in table 4.1 (4.5)put into evidence the aspect of the cavitation eroded areas.Regardless of the maintenance duration, the erosion is uniformly produced on the entire exposed surface but has reduced depth for the heat treatment with 25 minutes duration.

Table4.1(4.5) Optic microscope photos for specimens quenched at 1050 $^{\circ}$C



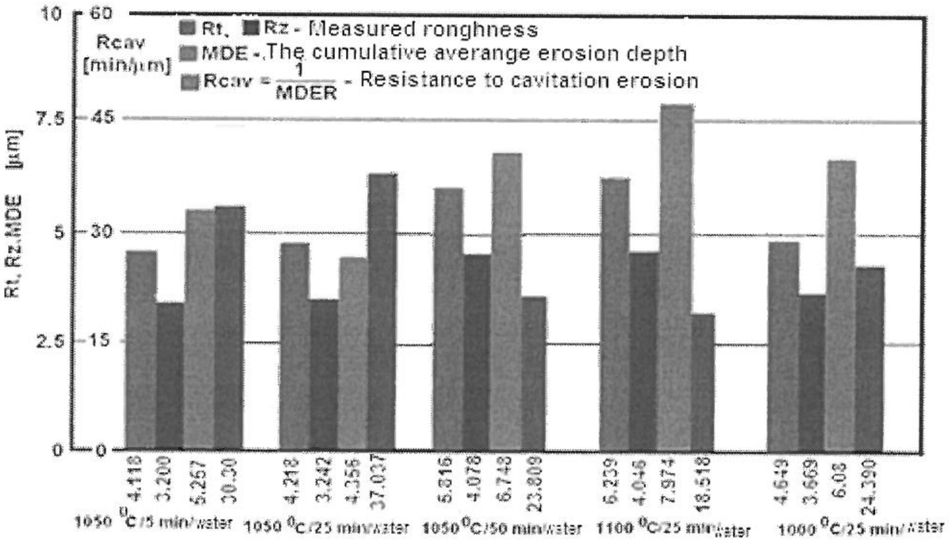


Fig. 4.7(4.24) Comparisons between cavitation erosion resistance and roughness (Rt, Rz, MDE, Rcav) for different heat treatments

Regardless of the used parameter R_{cav}, MDE, R_t or R_z, the diagram in fig.4.7 (4.24)show that for volumie heat treatments the best results are obtained for 1050 °C/25 min/water.

5. INFLUENCE OF THERMO-CHEMICAL NITRATION TREATMENT UPON CAVITATION EROSION RESISTANCE

Thermochemical treatments are processes of enriching a superficial layer with a given chemical element (frequently C, N, Br, Al), through the atomic diffusion of an external environment found to a high temperature.The procedure consist in heating the parts, at a given temperature, in a liquid or gaseous environment which release easily the atoms of the enrichment element, followed by the maintenance at the established temperature with ulterior cooling [39, 112].The nitration in gaseous environment represent the thermo-chemical treatment for enrichment in nitrogen the superficial layers, having as result the formation of nitrates which give a significant increase of the hardness [112]. The nitration used by us was realized in conformity with the diagram presented in fig. fig.5.1 (5.2) by using a furnace with nitrogen controlled atmosphere.

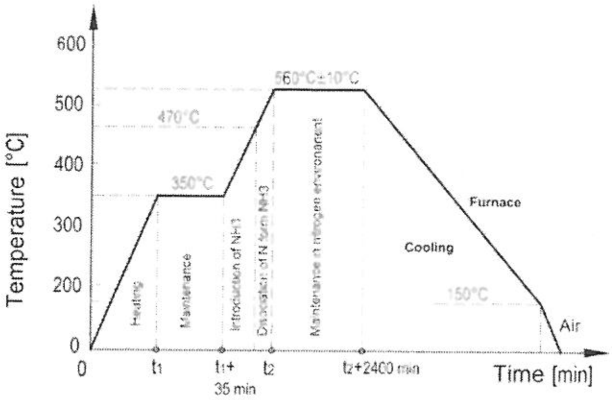
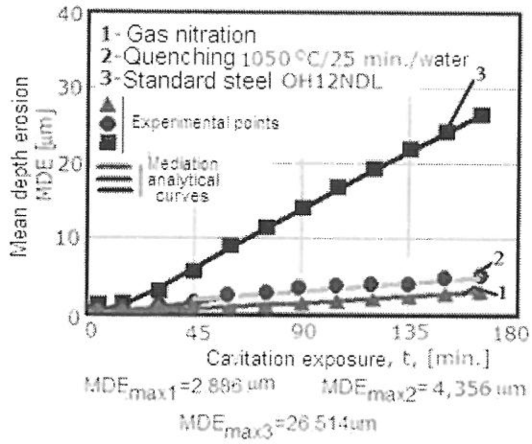
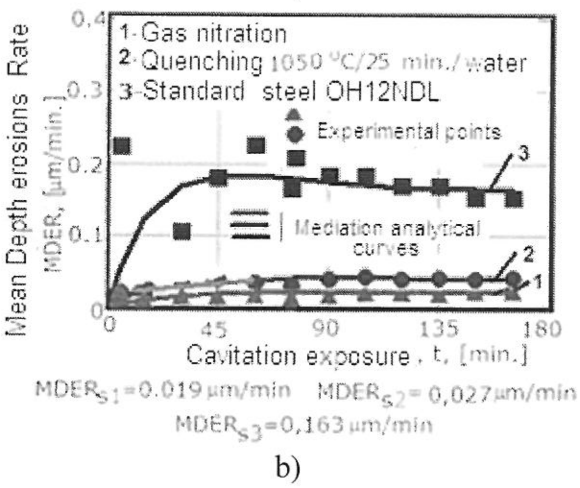


Fig.5.1 (5.2) Diagram of the gas nitration thermo-chemical treatment

To found out the cavitation erosion resistance of the stainless steelX5CrNi18-10 both after the nitration procedure and the quenching at 1050 °C with 25 minutes maintenance followed by cooling in water, in fig.5.2 (5.10) there are given the comparisons with the standard stainless steel OH12NDL.



a)

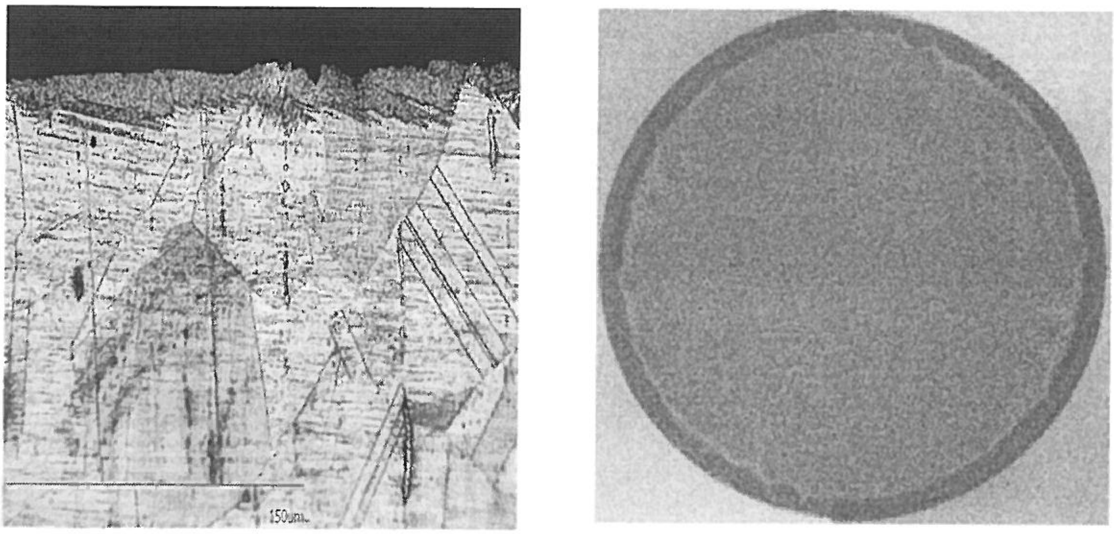


b)

Fig.5.2 (5.10) Cavitation erosion characteristic curves

a) Mean depth erosion against time exposure
b) Mean depth erosion rate against time

In fig.5.3 (5.12) is presented the microstructure for the specimens subjected to gas nitration and afterwards exposed 165 minutes to cavitation erosion.

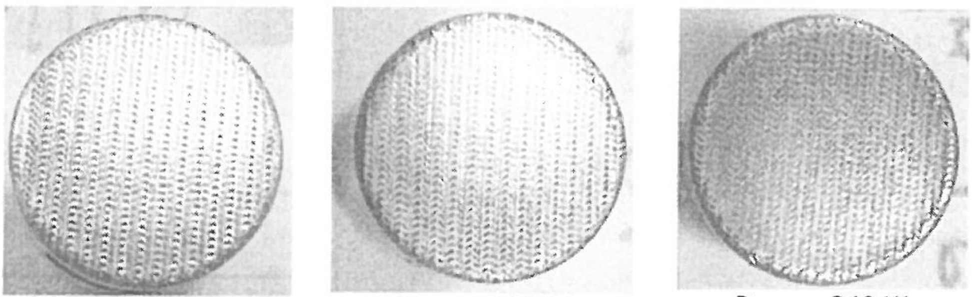


a) b)

Fig.5.3 (5.12) Images of the eroded area, after 165 minutes of cavitation, for a gas nitrated specimen: a) optic microscopy; b) general view of the eroded area

The application ofgas nitration thermo-chemical treatment for the steel X5CrNi18-10, with preponderant austenitic structure, does not significant modify the volume chemical composition but assure an important increase to cavitation erosion. The behavior of this layer become much higher than that of the steelOH12NDL used frequently for hydraulic turbines and even greater than the cavitation erosion resistance obtained throughquenching at 1050°C/25 min/water.

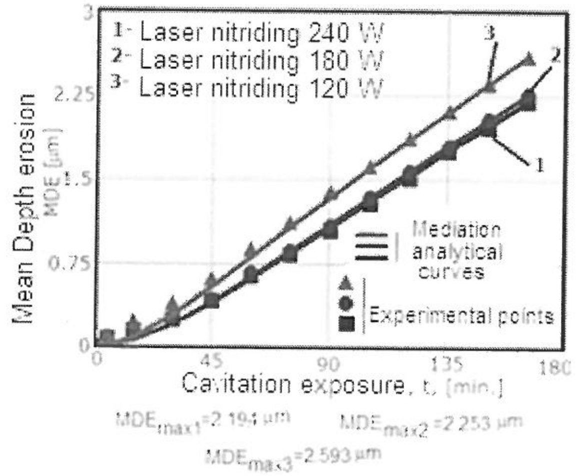
The nitration with laser beams was done in three different regimes, mainatining constant the pulsation duration. In fig. 5.4 (5.17) are presented the laser nitrated area of tree specimens, for different values of the power impulse.



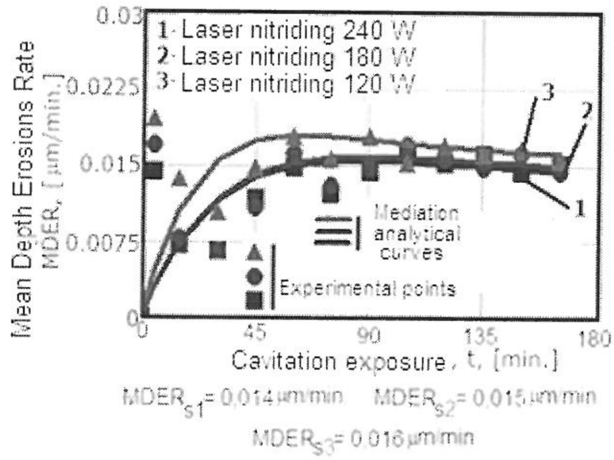
P_{impuls}= 120 W P_{impuls}= 180 W P_{impuls}= 240 W

Fig.5.4(5.17)Laser nitrated surface appearance, for different powers

In fig.5.5(5.23) are compared the cavitation erosion characteristic curves. The experimental values points figured are the mean values for three specimens tested.



a)



b)

Fig.5.5 (5.23) Cavitation erosion characteristic curves

a) Mean depth erosion against time exposure
b) Mean depth erosion rate against time exposure

The nitration techniquewith laser beams determines the forming of striate layers, with increased hardness, having excellent behavior to cavitation erosion. For a rapid evaluation of the differences to cavitation erosions realized through both nitration procedures it was constructed the histogram in fig.5.6 (5.24).

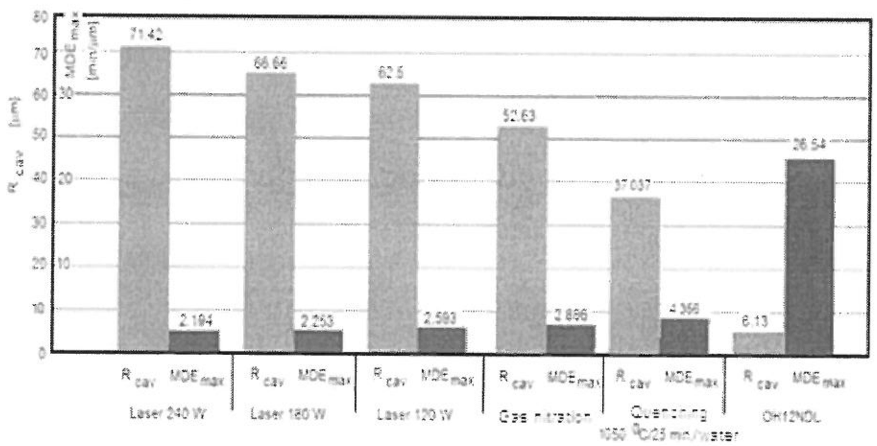


Fig.5.6 (5.24) Comparison of the cavitation erosion resistance for different treatments

The data from the histogram presented in fig. 5.6 (5.24) show that, regardless of the parameter considered (R_{cav}or MDE_{max}), through laser nitration at 240 W there is obtained the maximum erosion resistance, respectively the minim depth of cavitation erosion.

6. A NEW CONCEPT FOR THE HIERARCHISATION OF THE STAINLESS STEELS IN CONCORDANCE WITH THE CAVITATION EROSION RESISTANCE

In this chapter is presented a new concept for ranking after cavitation erosion resistance the stainless steels investigated in the TPU Cavitation Laboratory. This concept is built on the diagram which give the correlation between the cavitation erosion resistances (R_{cav}) and the scale and form parameters for the analytic equations of the characteristic curves MDE (t) and MDER (t) and was presented at the ICAS Conference 2016 [34].

Below are resumed the relations established by Bordeasu and coworkers [14, 29, 78, 83],underlying the construction of the curves MDE (t) and MDER(t) which allow the determination of the parameters used for the evaluation /comparison the resistance to the vibrating cavitation erosion:

- for the mean depth erosion

$$MDE\,(t) = A\cdot t\cdot(1\text{-}e^{-B\cdot t}) \qquad (6.1)\ \ [(6.18)]$$

- for the mean depth erosion rate

$$MDER(t) = A\cdot(1\text{-}e^{-B\cdot t}) + A\cdot B\cdot t\cdot e^{-B\cdot t} \qquad (6.2)\ [(6.19)]$$

where: ***A*** is a scale parameter,statistic established for the construction of the approximation curve with the condition to obtain minimum scatter of the experimental points from the curve.

B is a form parameter.

The normalized cavitation erosion resistance R_{ns}has the expression:

$$R_{ns} = v_s/v_{se} \qquad (6.3)\quad [(6.20)]$$

where:

v_s–is the value at which the researched material erosion rate tends to stabilize (whatever we report the eroded mass, the eroded volume or the penetration depth);

v_{se}–is the value at which the standard material tends to stabilize (for our laboratory the stainless steel OH12NDL).

The materials used for constructing the new concept are stainless steels (cast and rolled) in an annealed state destined for manufacturing pieces exposed to intense cavitation.

In table 6.1(6.5)is presented the ranking after normalized cavitation erosion resistance established by Jurchela şi Karabenciov [78, 83],in which isincluded also the steel investigated in our thesis.

Table 6.1 (6.5)Steel ranking after the normalized cavitation erosion resistance [78,83]

Cavitation resistance	Material	R_{ns}	Structure
Super-resistant< 0,2	C1Cr12Ni6	0,11	60%A+40%M
Excellent [0.2 ÷ 0.4)	C1Cr6Ni10	0,24	32% M + 68% A
	C1Cr12Ni10	0,29	100 %A
Very good	C1Cr10Ni10	0,44	100% A

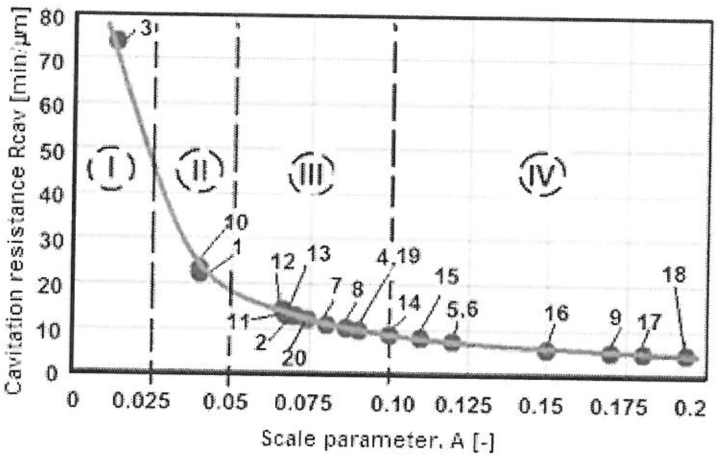
[0,4 ÷ 0,8)	C1Cr18Ni10	0,43	98% A + 2% F
	C1Cr24Ni10	0,41	81% A + 19% F
	X5CrNi18-10	0,54	88% A+12 %F
	C036Cr13Ni10	0,73	55% M + 45% A
	C036Cr14Ni10	0,76	30% M + 70% A
	C1Cr12Ni2	0,51	90%M+10%F
	C036Cr12Ni6	0,62	100 %M
	C036Cr12Ni8	0,59	90 %M +10%A
	C030Cr12Ni6	0.57	100 % M
Good [0,8 ÷ 1,6)	OH12NDL	1,0	84%M+16%F
	C036Cr16Ni10	0,92	100% A
	C036Cr18Ni10	1,05	93% A + 7% F
	C1Cr12Ni05	0,88	75% M+ 25 % F
	C036Cr12Ni2	0.88	55 %M+45 %F
	C036Cr12Ni4	0.88	86%M+14 %F
	C030Cr12Ni2	1.14	40%M+60%F

In table 6.2 (6.6)are given the values of the parameters for scale ***A*** and form ***B*** for the analytical mediation curves as well as the value of cavitation resistance $\mathbf{R_{cav}}$, whereby it is established the compliance of the ranking after the parameter $\mathbf{R_{ns}}$, from Table 1.

Table 6.2(6.6) Steel ranking after the normalized cavitation erosion resistance and comparisons with the shape and scale parameters of the analytic curves

Cavitation resistance	Material	R_{cav}	Parameter A	Parameter B
Super-resistant	C1Cr12Ni6	78	0.013	0.027
Excellent	C1Cr6Ni10	23	0.04	0.022
	C1Cr12Ni10	22	0.037	0.024
Very good	C1Cr10Ni10	13	0.067	0.013
	C1Cr18Ni10	13	0.068	0.014
	C1Cr24Ni10	14	0.066	0.025
	X5CrNi18-10	12	0.072	0.019
	C036Cr13Ni10	9	0.10	0.017
	C036Cr14Ni10	10	0.09	0.015
	C1Cr12Ni2	13	0.07	0.018
	C036Cr12Ni6	11	0.08	0.015
	C036Cr12Ni8	10	0.09	0.013
	C030Cr12Ni6	10	0.086	0.016
Good	OH12NDL	5	0.17	0.018
	C036Cr16Ni10	6	0.15	0.015
	C036Cr18Ni10	5	0.18	0.02
	C1Cr12Ni05	8	0.11	0.018
	C036Cr12Ni2	7	0.12	0.014
	C036Cr12Ni4	7	0.12	0.014
	C030Cr12Ni2	5	0.191	0.026

The figure 6.1 (6.10) show the variation of the of cavitation erosion resistance against the scale parameters. It is to be observed that together with the increase of the parameter A the steel cavitation erosion has an exponential decreasing tendency.



I Cavitation erosion super resistant steels
II Cavitation erosion excellent steels
III Cavitation erosion very good steels
IV Cavitation erosion good steels

Fig.6.1 (6.10) Correlation between cavitation erosion resistance and the scale parameter A 1- C1Cr12Ni10, 2- C1Cr12Ni2, 3- C1Cr12Ni6, 4- C036Cr14Ni10, 5-C036Cr12Ni2, 6-C036Cr12Ni4, 7- C036Cr12Ni6, 8- C036Cr12Ni8, 9- OH12NDL, 10- C1Cr6Ni10, 11-C1Cr10Ni10, 12- 1Cr18Ni10, 13- C1Cr24Ni10, 14- C036Cr13Ni10, 15- C1Cr12Ni05, 16-C036Cr16Ni10, 17- C036Cr18Ni10, 18- 030Cr12Ni2, 19- C030Cr12Ni6, 20- X5CrNi18-10

Taking into consideration the ranking in the tables 6.1-6.2 (6.5-6.6), it is to be observed the parameter A can be used for a similar ranking, respecting the same principle (by doubling the interval limits at the transition from one class to another.

Figure 6.2 (6.11) show that the form parameter from the relations (6.1) and (6.2) [(6.18) and (6.19)] do not have a significant influence upon the cavitation erosion resistance and cannot be used for ranking.

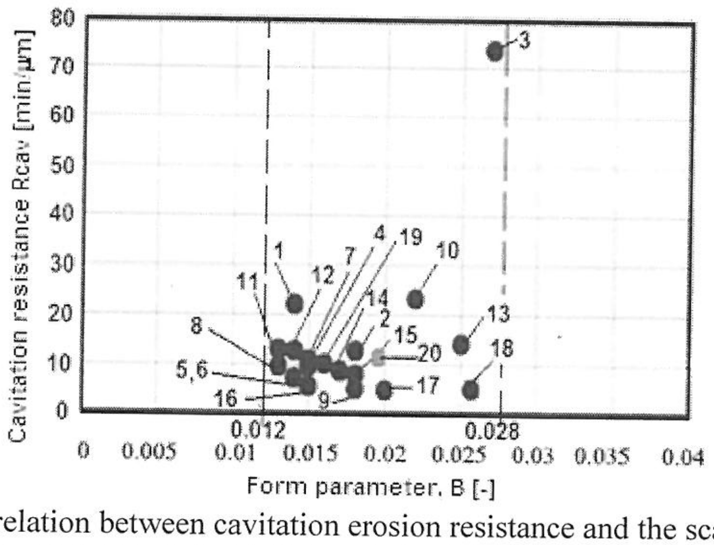


Fig.6.2 (6.11) Correlation between cavitation erosion resistance and the scale parameter B 1-C1Cr12Ni10, 2- C1Cr12Ni2, 3- C1Cr12Ni6, 4- C036Cr14Ni10, 5-C036Cr12Ni2, 6-C036Cr12Ni4, 7- C036Cr12Ni6, 8- C036Cr12Ni8, 9- OH12NDL, 10- C1Cr6Ni10, 11-C1Cr10Ni10, 12- C1Cr18Ni10, 13- C1Cr24Ni10, 14- C036Cr13Ni10, 15- C1Cr12Ni05, 16-C036Cr16Ni10, 17- C036Cr18Ni10, 18- C030Cr12Ni2, 19- C030Cr12Ni6, 20- X5CrNi18-10

The scale parameter A from the equations (6.1) and (6.2) [(6.18) and (6.19)], which allow the construction of the erosion characteristic curves, constitutes a ranking criterion for the material resistance to cavitation erosion being similar to the normalized resistance R_{ns}. The proposed concept, has as basis the relations established by Bordeasu and coworkers, and offer a rapid evaluation of the cavitation erosion resistance.

7. FINAL CONCLUSIONS.PERSONAL AND ORIGINAL CONTRIBUTIONS.RESEARCH PERSPECTIVES

1. All the general conclusions formulated by the previous researchers remain valid [89,] [95], [131-132].
2. The researches in the field of cavitation erosions must be continued, becausetill to the present moment, there have not been found hydrodynamic methods, materials and technological procedures to eliminate completely the wear produced by cavitation.
3.The heat treatments such as quenching, nitration in gas or with laser beams applied to austenitic stainless steels used in the manufacturing of butterfly valves can increase sustantially the running time between two succesive repair works.
4.The use of thermochemical procedures for nitration with gas or appling the laser beam procedure, even beeing extremelly efficient are sometimelimited in practice as a result of the geometric complexity of the piece. They are easy to be applied for pieces with simple geometric shape such as those used in the construction of buterfly valves.

The personal contributions realized by experimental researches and numerical modelling of the flow in butterfly valves, can be synthetizated as :
1. Putting into evidencethe existance of the cavitation phenomenon in the butterfly valve with biplane disc with the diameter of 2.8 m, at angles over $30^0$for a maximum flow capacity of Q_{max}=84.18 m^3/s respectively angles over 50°for a nominal flow capacityQ_n=61 m^3/s, using the simulation through the module Flow Simulation intergated in the interface of the application Solid Works.
2. We showed that by modifying the heating temperature for putting into solution (1000 °C, 1050 °C, 1100 °C), maintaining unchanged the steady time-keeping (25 min) the modification of cavitation erosion is insignificant for the inferior limit (1000 °C) but became important if the temperature is at the superior limit (1100 °C).
3. We showed that for the researched austenitic stainless steel X5CrNi18-10,heated at 1050 °C with a holding mainenance of 25 min. followed by cooling in water it was obtained a reduction of the mean dept erosion rate of approximately 1.74 times with regard to the 50 min. mainaining and 2 times with regard for 5 min. maintenance.
4. Through the images of the eroded areas obtained with optical microscope but also with a scanning electron microscope were put into evidence ductile fractures as well as the fact that the cavitation cracks are localized either on the grain boundaries or along the annealing mackles. The scanning electron microscopy upon the cross sections of the eroded area put into evidence that the cavern occur (for all the applied volume treatments) in the ferrite islands or on the separation line of these islands and the structural matrix. For the final attack periods in the ferrite zones appear eroded zone in the form of branches or rivers.
5. There have been obtained important increases of the cavitation erosion resistance for nitrated surfaces, regardless of the type of thermo-chemical treating (in gas or with laser) as the result of hardness increases to approximate 860 – 880 $HV_{0.05}$(for nitrating with gas) and approximate 550...600 $HV_{0.3}$ (for nitrating with laser), without modifying significant the chemical composition of the basic material but only by enriching with nitrogen a superficial layer.
6. Throughthe three laserregimes used for nitration, for the same puls duration (8 ms) it has been put into evidence the effect of the impulse power upon the nitrated layer exposed to

cavitation. Using the power of 240 W it was realized the maximum resistance to cavitation erosion, with approximate 14% greater than for 180 W, 7 % greater than for 120 W, with approximate 32% than gas nitration and 3,55 greater than for quenching at 1100 °C/25 min/water and 12 times greater than the resistance of the stainless steel OH12NDL, with good results in Laboratory and field runing.

7. Realizing a new concept for a rapid evaluation of the cavitation erosion resistance using only the value of the scale parameter A, from the equations established by Bordeasu and coworkers for describing the cavitation erosion characteristic curves.

The final conclusion is that the doctoral degree thesis has an interdisciplinary character (mechanical engineering-materials engineering) which is part of the actual international trend to increase the lifetime of the mechanical equipment.

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