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The use of R_z roughness parameter for evaluation of materials behavior to cavitation erosion

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Abstract. It is well known that the cavitation eroded surfaces have a porous appearance with a pronounced roughness. The cause is the pitting resulted from the impact with the micro jets as well as the shock waves both determined by the implosion of cavitation bubbles. The height and the shape of roughness is undoubtedly an expression of the resistance of the surface to the cavitation stresses. The paper put into evidence the possibility of using the roughness parameter R_z for estimating the material resistance to cavitation phenomena. For this purpose, the mean depth erosion penetration (MDE-parameter, recommended by the ASTM G32-2010 Standard) was compared with the roughness of three different materials (an annealed bronze, the same bronze subjected to quenching and an annealed alloyed steel), both measured at four cavitation erosion exposure (30, 75, 120 and 165 minutes). The roughness measurements were made in 18 different zones, disposed after two perpendicular diameters, along a measuring lengths of 4 mm. The results confirm the possibility of using the parameter R_z for estimating the cavitation erosion resistance of a material. The differences between the measured values of Rz and those of the characteristic parameter MDE are of the same order of magnitude as those obtained for MDE determination, using more samples of the same material.

1. Introduction

In practice, for hydraulic equipment the evaluation of the cavitation damage is done on the base of both the area and the volume eroded. The volume is frequently appreciated upon the consumed electrodes volume used for the repair work [1-3]. In research laboratories the evaluation is more complex, being used specialized devices which allow to obtain details upon the cavitation erosion evolution. In our laboratory, this device was realized upon the recommendations ASTM G32-2010 Standard and the tests are conducted following also the recommendations of this standard [4]. In parallel, many researchers are interested also by the possibility to evaluate the cavitation erosion resistance by using the roughness parameters [5-10]. Till now, there were presented in various papers the profile diagram of the roughness's [11], [9] but till the present it was not obtained a clear method to correlate directly the cavitation erosion with the roughness. The motive is the implication of different factors such as: the irregular shape of the roughness's in materials with different physical-mechanical parameters and various structures as well as the complexity of the cavitation bubble implosions [9], [11-15].

From this motive, the researchers working in the Cavitation Laboratory of Timisoara Polytechnic University have realized, in the last period, beside the cavitation erosion resistance with the well-known methods also researches about the eroded surfaces. The profile diagram was obtained using a Mitutoyo device after the final stage of cavitation erosion [8], [11]. All materials were tested in a cavitation erosion device which respect integrally the conditions imposed by the ASTM G32-2010 Standard. It was reached the conclusion that between the roughness parameter R_z and the MDE value exist a good dependence which allow to use R_z for the evaluation of materials subjected to cavitation erosion.

2. Analyzed materials

In order to obtain a reliable conclusion, for the beginning, there were chosen three different materials which were also subjected to heat treatments for increasing the resistance to cavitation erosion. These materials are:

- alloyed steel 16MnCr5 – annealed and carburized;
- CuAl10Ni5Fe2.5Mn1 - bronze subjected to volume quenching (the cavitation erosion of this steel was carefully analyzed in the doctoral degree thesis of eng. Oancă [14], and in the present work was subjected to new cavitation erosion experiments in order to measure the roughness parameters);
- alloyed steel 42CrMo4 (DIN 17200) - in annealed state (this steel is used for manufacturing some details of the hydraulic control devices).

3. Experimental procedure. Results and discussions

For each material, with the exception of steel 16MnCr5 – annealed and carburized, there were tested in the Standard Cavitation Erosion Device three specimens in agreement with the G32-2010 Standard and the laboratory customs [12], [9], [10], [16]. For one specimen the eroded surface was divide in 9 square zones (one in the central part and the others on two concentric circles) in which there were measured with the Mitutoyo device the roughness R_z on two perpendicular diameters (in total 18 measurements), in conformity with Figure 1. Those measurements were realized after (0, 30, 75, 120 and 160) minutes of cavitation exposure. Thus for each specimen were realized 90 measurements. In Table 1 are presented images with the cavitation erosion evolution, for the 5 measured times.

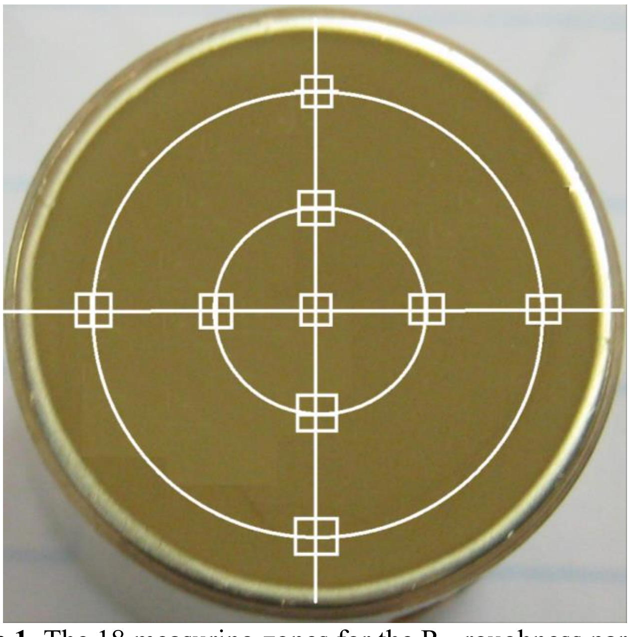
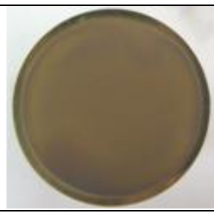
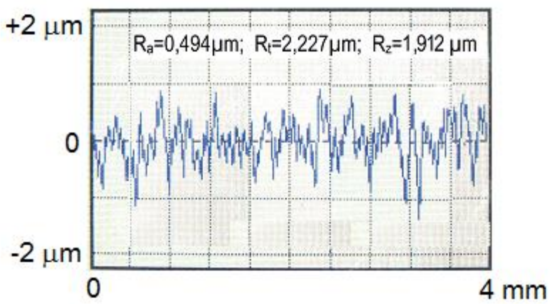


Figure 1. The 18 measuring zones for the R_z, roughness parameter

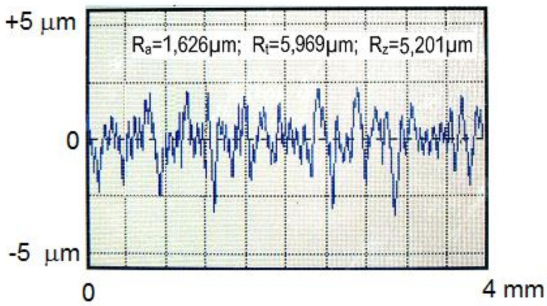
For each specimen, in Figures 2-4 is given four diagrams with the profile of the eroded area obtained with the Mitutoyo apparatus. It is presented the central area in which the greatest erosion occurs.

Table 1. Images of the cavitation erosion evolution

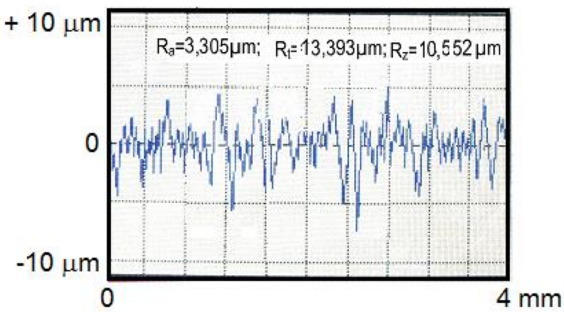
Cavitation exposure in minutes				
0	30	75	120	165
16MnCr5 steel – annealed and carburized				
				
CuAl10Ni5Fe2.5Mn1- bronze volume quenched (procedure described in [10])				
				
42CrMo4 steel – annealed				
				



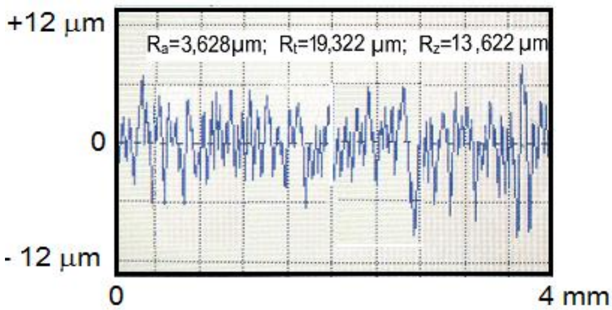
a) 30 minutes



b) 75 minutes

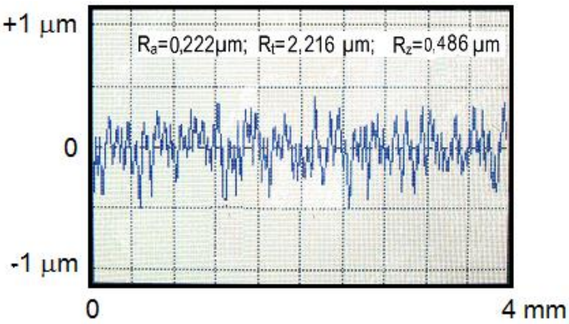


c) 120 minutes

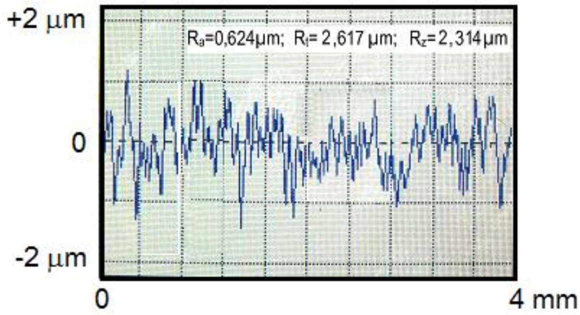


d) 165 minutes

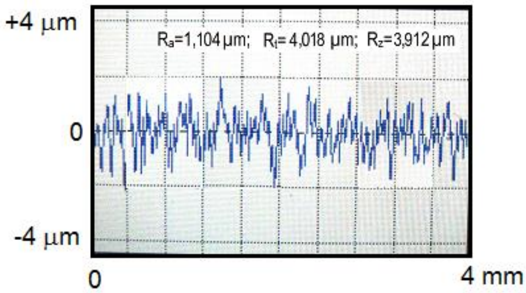
Figure 2. Mitutoyo roughness measurements for different exposure (Steel 16MnCr5-annealed and carburized)



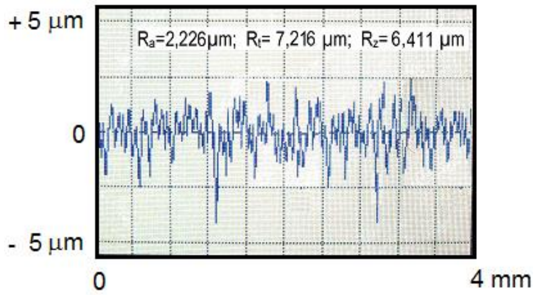
a) 30 minutes



b) 75 minutes

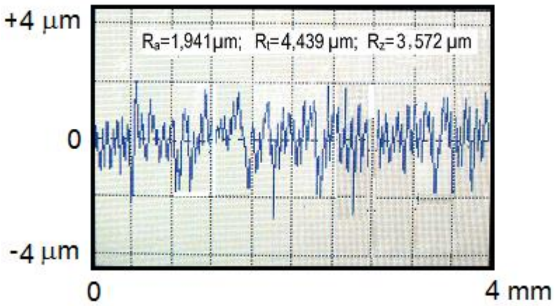


c) 120 minutes

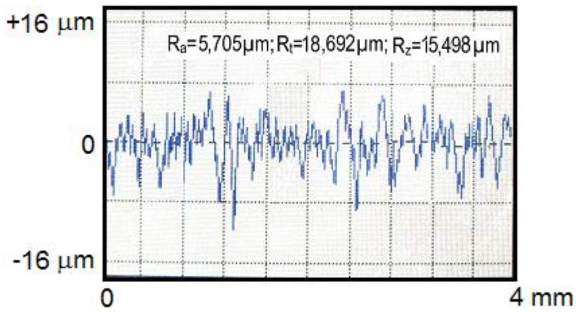


d) 165 minutes

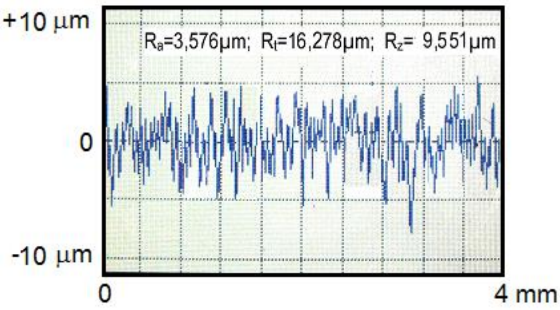
Figure 3. Mitutoyo roughness measurements for different exposure (CuAl10Ni5Fe2.5Mn1-TT bronze)



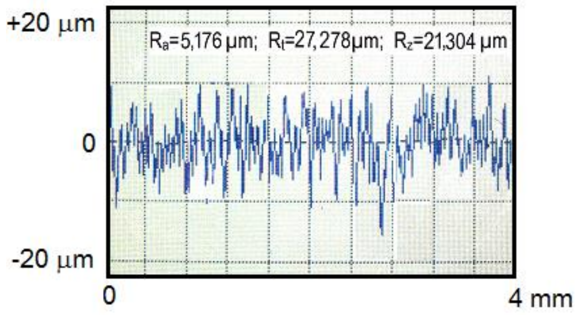
a) 30 minute



b) 75 minute



c) 120 minute



d) 165 minute

Figure 4. Mitutoyo roughness measurements for different exposure (42CrMo4 alloyed steel)

In Tables 2-4 are given the 18 values of the R_z parameter as well as the mean values for all the 9 measuring zones presented in Figure1. The parameter R_z gives the closer value to the mean depth erosion MDE [8], [15].

Specification: in MDE (t) diagrams, are presented the computed mean values of penetration for the entire area subjected to cavitation erosion.

Table 2. The values of parameter R_z [μm] (16MnCr5 steel-annealed and carburized)

0 min.	30 min.		75 min.		120 min.		165 min.	
Measured	Measured	Mean	Measured	Mean	Measured	Mean	Measured	Mean
0.02	1.488		5.943		9.925		13.694	
0.02	1.721		5.672		9.841		13.589	
0.02	1.698		5.011		10.153		13.715	
0.02	1.822		5.352		9.953		13.512	
0.02	1.751		5.224		9.942		13.672	
0.02	1.771		5.932		10.281		13.883	
0.02	1.834		5.725		10.185		13.516	
0.02	1.811		5.901		9.811		13.703	
0.02	1.831	**1.781**	5.211	**5.562**	9.889	**10.123**	13.011	**13.277**
0.02	1.792		5.867		9.921		13.785	
0.02	1.761		5.825		9.924		13.653	
0.02	1.699		5.021		9.872		13.901	
0.02	1.602		5.724		10.212		13.504	
0.02	**1.912**		**5.201**		**10.552**		**13.622**	
0.02	1.756		5.411		9.901		12.672	
0.02	1.842		5.103		9.952		13.443	
0.02	1.795		5.972		10.425		13.362	
0.02	1.587		5.895		9.898		13.198	

Table 3. The values of parameter R_z [μm] (Bronze CuAl10Ni5Fe2.5Mn1-TT)

0 min.	30 min.		75 min.		120 min.		165 min.	
Measured	Measured	Mean	Measured	Mean	Measured	Mean	Measured	Mean
0.02	0.425		2.233		4.071		6.208	
0.02	**0.486**		**2.314**		**3.912**		**6.411**	
0.02	0.493		2.021		4.115		6.118	
0.02	0.488		2.225		4.071		6.189	
0.02	0.525		2.146		4.104		5.998	
0.02	0.421		2.306		3.896		6.385	
0.02	0.511		2.198		3.903		6.012	
0.02	0.412	**0.455**	2.187	**2.316**	3.845	**3.941**	6.214	**6.14**
0.02	0.385		2.279		4.104		6.142	
0.02	0.401		2.323		4.202		6.421	
0.02	0.447		2.365		3.825		5.892	
0.02	0.411		2.402		3.925		6.141	
0.02	0.489		2.065		4.143		6.272	
0.02	0.443		2.204		4.059		6.301	
0.02	0.407		2.199		3.809		6.175	
0.02	0.491		2.285		3.998		6.007	
0.02	0.489		2.351		3.642		5.901	
0.02	0.501		2.389		4.188		6.415	

Table 4. The values of parameter R_z [μm] (42CrMo4 alloyed steel)

0 min.	30 min.		75 min.		120 min.		165 min.	
Measured	Measured	Mean	Measured	Mean	Measured	Mean	Measured	Mean
0.02	3.44		9.46		15.41		21.24	
0.02	3.375		9.375		15.521		21.272	
0.02	3.425		9.285		15.495		21.181	
0.02	3.555		9.572		15.312		21.239	
0.02	3.604		9.369		15.422		21.248	
0.02	3.402		9.522		15.495		21.421	
0.02	3.476		9.421		15.467		20.918	
0.02	3.421		9.389		15.502		21.361	
0.02	3.446	**3.469**	9.578	**9.432**	15.461	**15.435**	21.311	**21.242**
0.02	3.618		9.422		15.456		21.255	
0.02	**3.572**		**9.551**		**15.498**		**21.304**	
0.02	3.501		9.344		15.421		21.325	
0.02	3.492		9.367		15.461		21.115	
0.02	3.366		9.403		15.401		21.192	
0.02	3.381		9.298		15.431		21.236	
0.02	3.471		9.574		15.431		21.278	
0.02	3.534		9.339		15.446		21.401	
0.02	3.411		9.501		15.417		21.092	

In the histograms presented in Figures 5-7 there are compared the measured mean values of R_z, for a single tested specimen, with the mean dept erosion values for three tested specimens. It resulted the following conclusions:

- before cavitation erosion tests the roughness has evidently a given value but the mean depth erosion is absent;
- for small exposure time (30-70 minutes) the difference is enough great, the MDE indicator having enhanced values than R_z;
- for long exposure time (120-165 minutes) the differences remains but are very small.

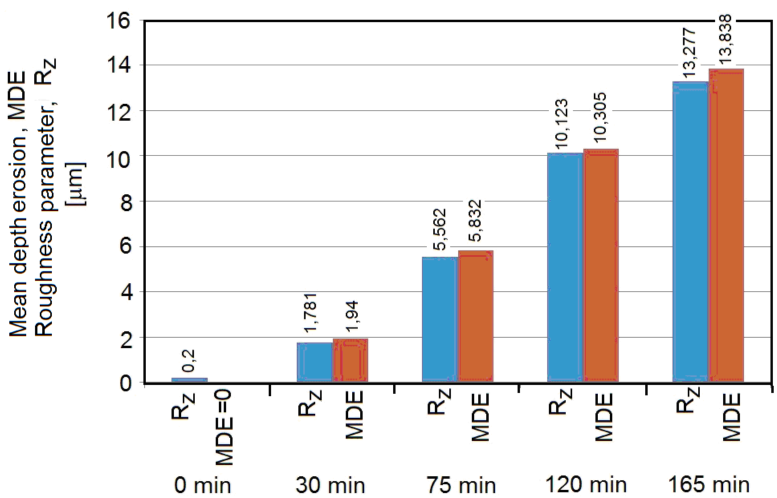


Figure 5. Comparison between the parameter MDE with the roughness R_z (16MnCr5 Alloyed steel – annealed and carburized)

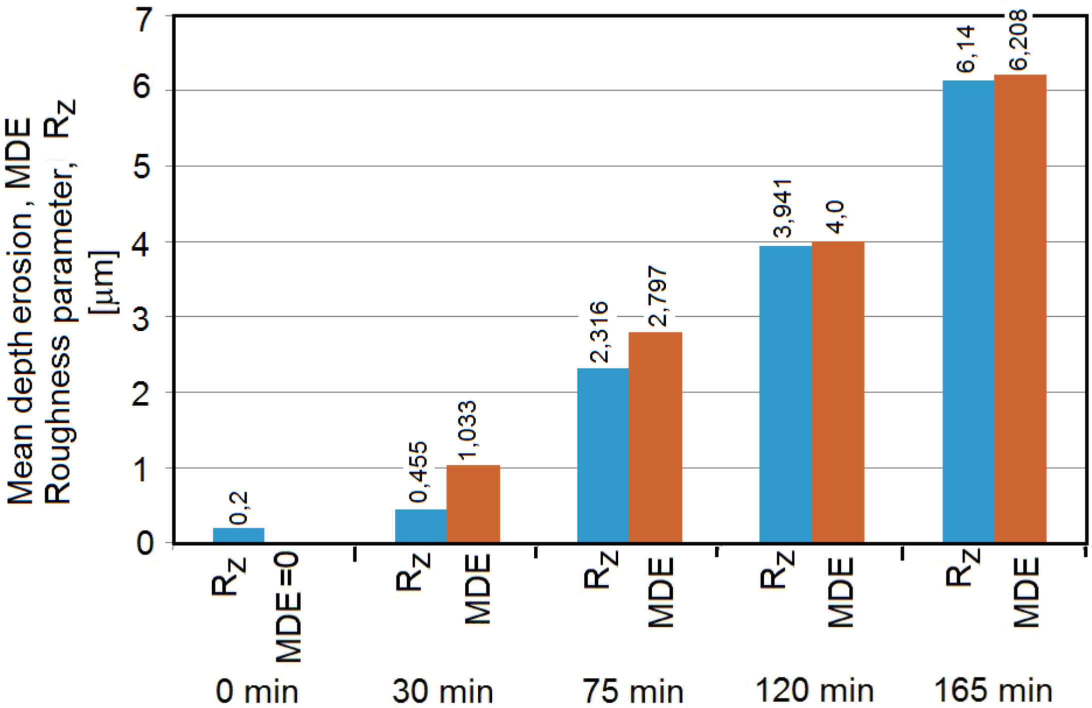


Figure 6. Comparison between the parameter MDE with the roughness R_z
(Bronz CuAl10Ni5Fe2.5Mn1M45–quenching and abatement, processed after [10])

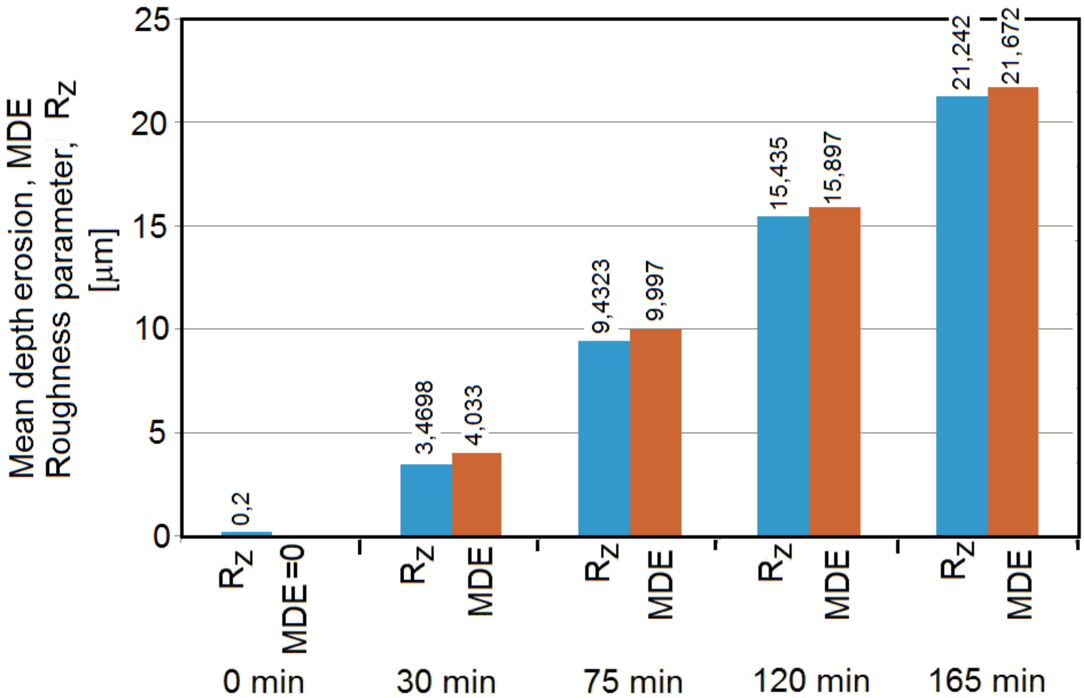
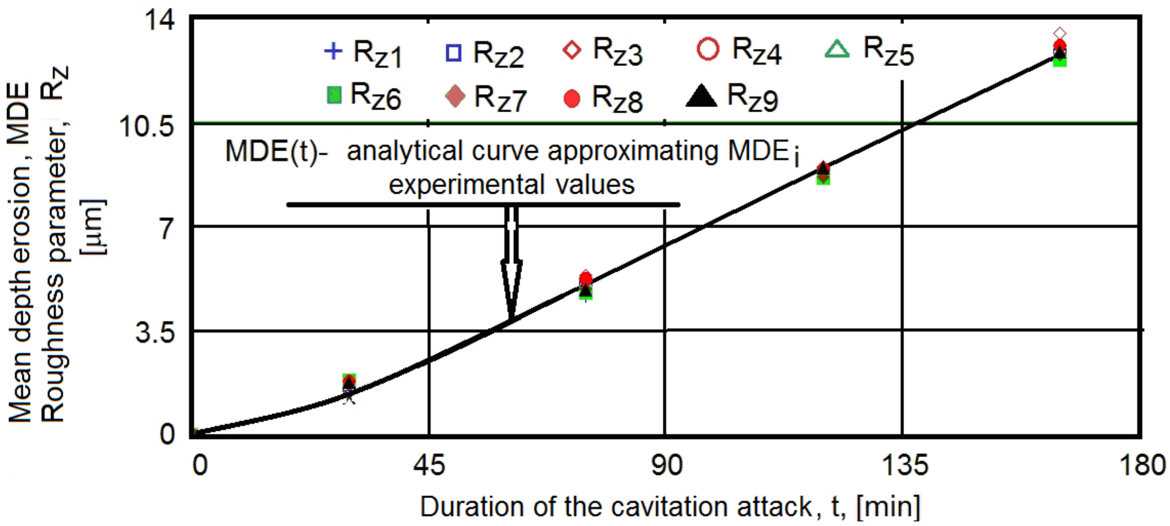


Figure 7. Comparisons between MDE and R_z roughness
(42CrMo4 steel –annealed state)

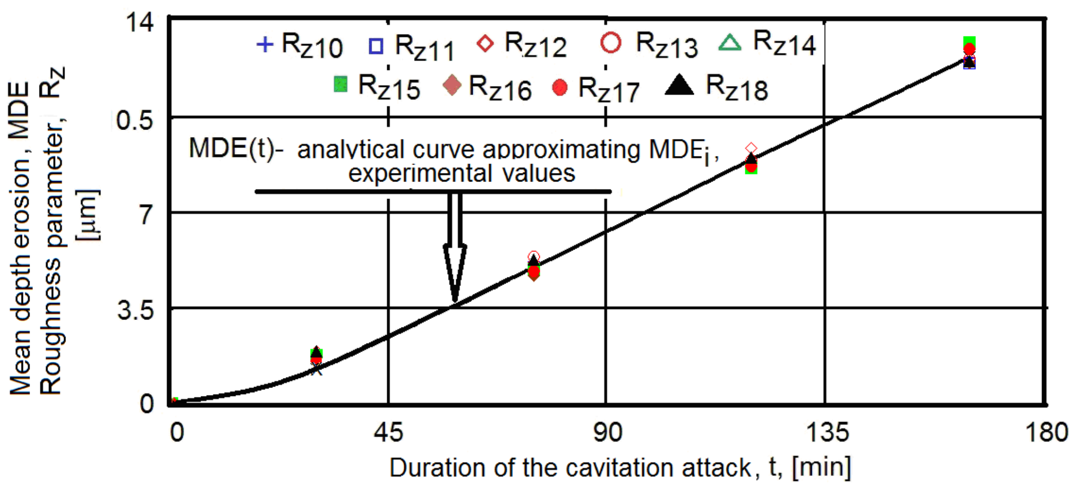
These differences have the following explanations: when the cavitation phenomenon appears (first 15-30 minutes) the metallic dust resulted from the manufacturing procedure, strongly inserted between the roughnesses as well as the sharp apexes are easily removed and the volume losses being great the mean depth erosion is also very great. As the exposure time increases the influence of this important mass loses decreases sharply and the differences became without importance.

For very long exposures (120-165) minutes the losses for the same interval of exposure decreases as result of the superficial layer hardening as a result of the stresses delivered by the implosion of the cavitation bubbles [5], [12], [13], [15]. These conclusions are in agreement also with the zone III (erosion attenuation) and zone IV (erosion stabilization) which appear in the curves mean depth erosion rate [17].

In the diagrams of Figures 8-10 are presented the mean depth erosion curves, realized with the statistical relation for each material, as well as the R_z measured values. It was found out that the scatter is very small having the order of magnitude of the MDE values.

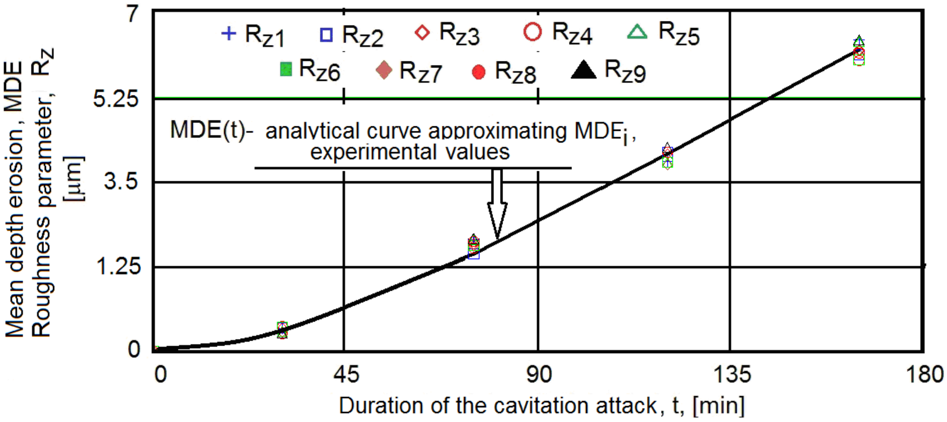


a) R_z values from 1 to 9

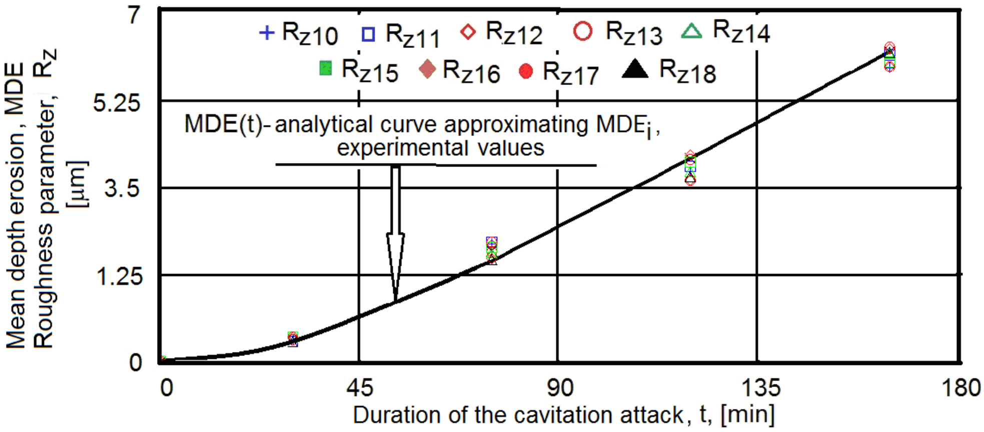


b) R_z values from 10 to 18

Figure 8. R_z parameter scatter from the curve approximating the experimental values of mean depth erosion – steel 16MnCr5-annealed and carburized

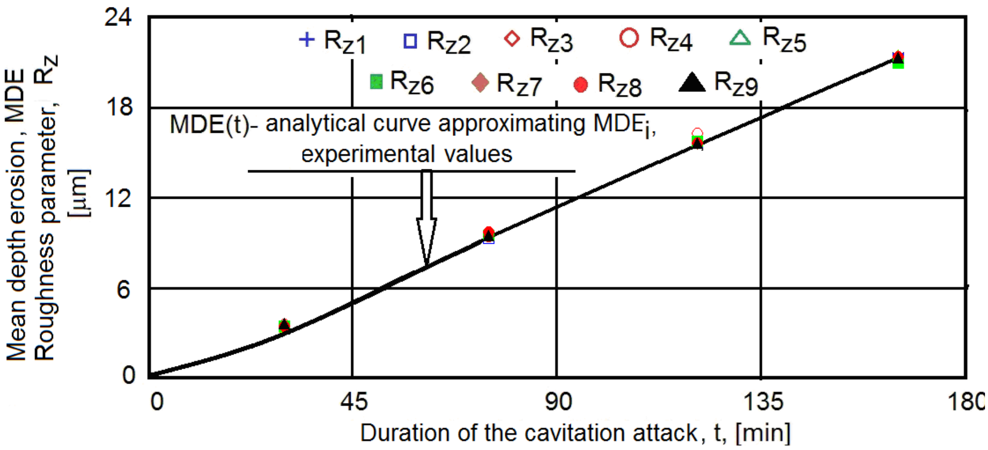


a) R_z values from 1 to 9



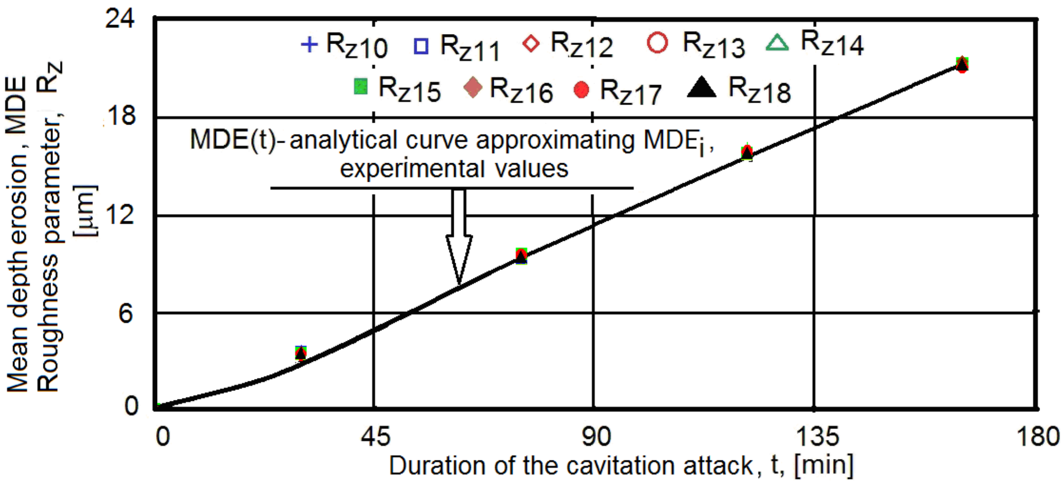
b) R_z values from 10 to 18

Figure 9. R_z parameter scatter from the curve approximating the experimental values of mean depth erosion - bronze CuAl10Ni5Fe2.5Mn1-TT



a) R_z values from 1 to 9

Figure 10a. R_z parameter scatter from the curve approximating the experimental values of mean depth erosion steel. 42CrMo4 –annealed



b) R_z values from 10 to 18

Figure 10b. R_z parameter scatter from the curve approximating the experimental values of mean depth erosion steel. 42CrMo4 –annealed

4. Conclusions

The profile diagrams, graphically recorded with the Mitutoyo device show that the roughness shape and level is given by the resistance of the material against cavitation stresses.

It was confirmed the possibility of using the R_z parameter to estimate the resistance to cavitation erosion. The differences obtained between the measured values of R_z and MDE (see Figures 8-10) does not exceed the differences realized by MDE test results for various samples manufactured from the same material and tested in equal conditions.

The R_z parameter has smaller values than MDE for the first minutes of attack. Those differences occur because in this time interval MDE has greater loss values by elimination of the dust remained between the roughnesses of the surface which cannot be quantified the profiles measured with the Mitutoyo device.

As a general conclusion we can say that measurements of the R_z parameter represent an excellent method to record the cavitation erosion of materials.

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