CORRELATION BETWEEN CAVITATION EROSION AND RANDOM FATIGUE PROPERTIES OF SELECTED STEELS

W.Będkowski*, G.Gasiak*, A.Lichtarowicz#, E.Macha*

The paper contains results of fatigue tests under uniaxial random loadings and tests of resistance to cavitational erosion. Three kinds of steel, 10HNAP, 18G2A, 15G2ANb were tested. The characteristics obtained were used for searching relations between those two effects. The analysis shows a strong correlation between fatigue life of the material under random loading and its resistance to cavitational erosion. The nonlinear regression relationship between the two phenomena were determined for all steels tested. They are the first quantitative results giving relations between these two destructive effects for the materials, determined so far.

1.INTRODUCTION

Cavitation erosion is a destructive process caused by the collapse of cavitation bubbles. During collapse shock waves are generated and if the collapse occurs near a solid boundary a microjet directed towards the wall is generated inside the bubble, Lichtarowicz (1). The microjet velocities can exceed easily 100 m/s. The distribution of the cavitation bubbles which collapse on the wall of material is random. It is probable therefore that this repeated impacts will produce a fatigue type material failure, Ahmed et al (2). The randomness of loading produced by cavitation and the random fatigue loading tests suggest that the two phenomena can be similar. The investigation of both phenomena may lead to a better understanding of both process and to a more informed selection of materials.

2.MATERIALS USED

The tests were carried out on samples of three structural steels: 10HNAP, 18G2A and 15G2ANb. Their chemical composition and their mechanical properties are given in Tables 1 and 2 respectively.

*Department of Mechanics and Machine Design, Technical Univ.of Opole, Poland,
#Department of Mechanical Engineering, University of Nottingham, UK.

TABLE 1- Chemical composition in % of tested steels

steel	C	Mn	Si	P	S	Cr	Cu	Ni	Nb	Fe
10HNAP	0.115	0.71	0.41	0.082	0.028	0.81	0.30	0.50	--	the rest
18G2A	0.180	1.30	0.45	0.040	0.030	0.30	0.20	0.20	--	the rest
15G2ANb	0.160	1.20	0.35	0.040	0.030	0.30	0.10	0.10	0.03	the rest

TABLE 2- Mechanical properties of tested steels

steel	static				fatigue (cyclic) lg N= A-m_σ lg σ_a			
	σ_Y[MPa]	σ_U[MPa]	E [GPa]	ν	σ_{af}[MPa]	m_σ	No[cycl.]	A
10HNAP	418	566	215	0.29	252	9.82	1286000	29.7
18G2A	358	533	210	0.30	204	7.91	1120000	24.3
15G2ANb	365	540	210	0.30	185	7.85	1106000	23.8

These steels have a fine-grain ferro - perlitic structure with ferrite dominating.

3.RANDOM FATIGUE TESTS

Uniaxial fatigue tests with random tension-compresion loading with zero mean stresses were carried out on several samples made from these steels at each load level. Random loading with zero mean value and dominating frequency 15 Hz and limiting frequency 50 Hz was generated using a matrix method produced on a microcomputer. The results of tests are presented in Fig.1.
The tests results were approximated by the following logarithmic function:

- for 10HNAP steel: $\lg T_{exp} = 26.97 - 10.19 \lg \sigma_{RMS}$ (1)

- for 18G2A steel: $\lg T_{exp} = 24.77 - 10.20 \lg \sigma_{RMS}$ (2)

- for 15G2ANb steel: $\lg T_{exp} = 22.85 - 10.01 \lg \sigma_{RMS}$ (3)

4.CAVITATION EROSION TESTS

Any submerged jet will cavitate provided that its velocity is sufficiently high and the ambient pressure downstream is sufficiently low. In a short cylindrical nozzle with a sharp inlet edge the jet separates and forms a contraction. As the upstream pressure p_1 is increased and the downstream pressure p_2 is kept constant cavitation will start in the vortex structures of the jet, bubbles will form also in region of high shearing around the jet. Both the bubbles and the vortex structures are carried downstream and eventually implode. Similarity of the cavitating flow is ensured if tests are carried at a constant cavitation number σ_{cav}:

$$\sigma_{cav} = (p_2-p_v)/(0.5\rho u^2) \quad (4)$$

where:u, ρ, p_v are the jet velocity,density and vapour pressure of liquid respectively.
For a nozzle:

$$\sigma_{cav} = (p_2-p_v)/(p_1-p_v) \approx p_2/p_1 \quad (5)$$

as $p_1-p_v = 0.5\rho u^2$ and $p_1 > p_2 >> p_v$.
A cavitating jet method is used to produce erosion. This method has been proposed and developed by one of the authors and is fully described in references (1) and ASTM (3). The intensity of cavitation can be changed by altering both pressures within the limits set by:

$$\sigma_{cav} = p_2/p_1 = \text{const.} \quad (6)$$

A number of samples of each steel were tested at a constant cavitation number σ_{cav} = 0.0144, temperature of 32°C and upstream pressures p_1 ranging from 19.45 MPa down to 12.5 MPa.
The sample was weighed on a laboratory balance weighing down to 0.01 mg. It was than mounted in the apparatus and exposed for a specified time at previously set pressure conditions. The sample was weighed again. The operation was repeated till the desired number of data was obtained to ensure Cumulative Erosion Rate (CER) was pasts its maximum. CER is defined as:

$$CER = \Delta m/T \quad [\mu g/s] \quad (7)$$

where: Δm - Cumulative Weight Loss [μg] and T - exposure time [s].
CER values as a function of time for the three steel were ploted. All graphs show the Peak Erosion Rates (PER) and the corresponding time to reach that peak T_{PER}. The values of both of these depend on the nozzle pressure p_1 when σ_{cav} is kept constant.
Fig.2 shows the variation of the nozzle upstream pressure as a function of the T_{PER}. The p_1 - T_{PER} graph is analogous to the Wöhler S-N graph for fatigue. The scale is logarithmic indicating variation can be expressed as:

$$T_{PER} \propto p_1^m \quad (8)$$

This relationship is represented by the following empirical equations (similar to T_{exp} - σ_{RMS} - for random fatigue tests - eq.1,2,3) for tested steels:

- for 10HNAP steel: $\lg T_{PER} = 9.96 - 4.59 \lg p_1$ (9)
- for 18G2A steel: $\lg T_{PER} = 9.51 - 4.47 \lg p_1$ (10)
- for 15G2ANb steel: $\lg T_{PER} = 8.47 - 3.87 \lg p_1$ (11)

5. DETERMINATION OF THE RELATIONSHIP BETWEEN CAVITATIONAL EROSION AND FATIGUE STRENGTH

From the observations surfaces of the specimens subjected to cavitational erosion and the eroded particles using SEM it results that destruction of the material while cavitation is strongly connected with fatigue. The course of cavitational erosion described in (2) and Ahmed et al (4) is similar to the course of fatigue described in Kocańda (5).

Distributions and amplitudes of the implode bubbles causing erosion are of a random character. Thus, determining the relations between the considered phenomena the authors assumed the results obtained under random loadings.The obtained results of fatigue tests, expressed by equations (1), (2) and (3), and tests of cavitational erosion, equations (9), (10) and (11), were applied for determination of the relationship between resistance to cavitational erosion and fatigue life under uniaxial random loadings for the tested materials.

For the purpose of comparative analysis the test results for both fatigue and erosion were normalized. The assumed normalizing quantities are given below.

1.For characteristic of resistance to cavitational erosion we assumed a mean value of the liquid pressures at the inlet, $\hat{p}_1$, used during tests and the corresponding time for obtaining the maximum erosion rate, T_{PER}, taken from eq. (9 - 11):

-for 10HNAP steel: $\hat{p}_1 = 16.14$ [MPa] and $T_{PER}(\hat{p}_1) = 26045$ [s] (from eq.9)

-for 18G2A steel: $\hat{p}_1 = 15.98$ [MPa] and $T_{PER}(\hat{p}_1) = 13490$ [s] (from eq.10)

-for 15G2ANb steel: $\hat{p}_1 = 15.36$ [MPa] and $T_{PER}(\hat{p}_1) = 7563$ [s] (from eq.11)

2.For fatigue characteristic we assumed a mean value of the standard deviations $\hat{\sigma}_{RMS}$ used in tests and the corresponding life $T(\hat{\sigma}_{RMS})$ from the regression equation:

-for 10HNAP steel: $\hat{\sigma}_{RMS} = 155.93$ [MPa] and $T(\hat{\sigma}_{RMS}) = 42077$ [s] (from eq.1)

-for 18G2A steel: $\hat{\sigma}_{RMS} = 88.49$ [MPa] and $T(\hat{\sigma}_{RMS}) = 81598$ [s] (from eq.2)

-for 15G2ANb steel: $\hat{\sigma}_{RMS} = 69.73$ [MPa] and $T(\hat{\sigma}_{RMS}) = 24967$ [s] (from eq.3)

The normalized test results for three steels are shown in Fig.3, where:

$$p_{1N} = \frac{p_1}{\hat{p}_1}, \quad \sigma_{RMSN} = \frac{\sigma_{RMS}}{\hat{\sigma}_{RMS}}, \quad T_N = \begin{cases} \dfrac{T_{PER}}{T_{PER}(p_1)} \\ \dfrac{T_{PER}}{T_{PER}(\hat{\sigma}_{RMS})} \end{cases} \qquad (12)$$

From the regression equations for both types of tests (eq.1,2,3 and 9,10,11) the relationships between pressure, p_1, and the standard deviation of the stress σ_{RMS} in fatigue tests were determined. They are:

- for 10HNAP steel: $\lg \sigma_{RMS} = 1.669 + 0.450 \lg p_1$ (12)
- for 18G2A steel: $\lg \sigma_{RMS} = 1.496 + 0.438 \lg p_1$ (13)
- for 15G2ANb steel: $\lg \sigma_{RMS} = 1.437 + 0.387 \lg p_1$ (14)

6.CONCLUSIONS

From the tests the following conclusions can be drawn:

1. Fatigue under random loadings and cavitation erosion of the steels tested can be expressed by mathematical models of the same type.
2. It has been shown that there is a linear relation in logarithmic scale between resistance of the steels tested to cavitation erosion and their fatigue strength under random loadings. They are the first quantitative relations between these two destructive phenomena found so far.

LITERATURE

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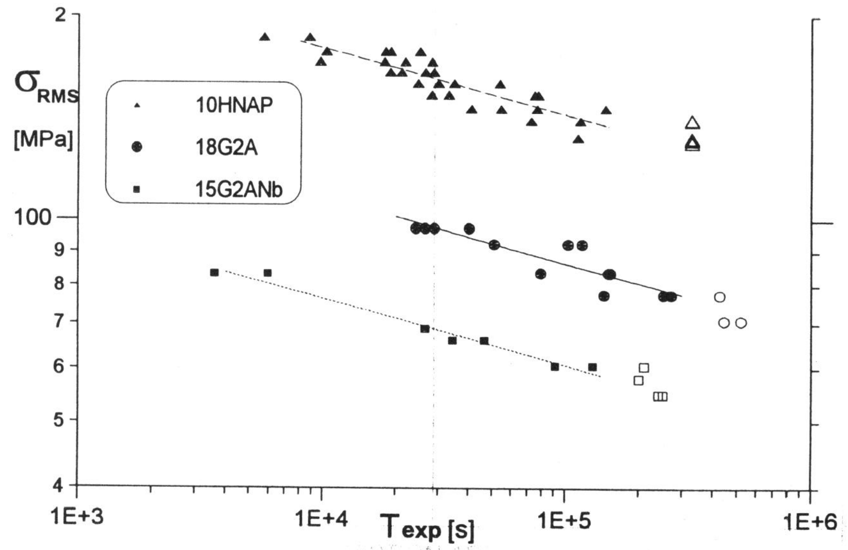

Fig.1.Fatigue test results under uniaxial random loading for three steels

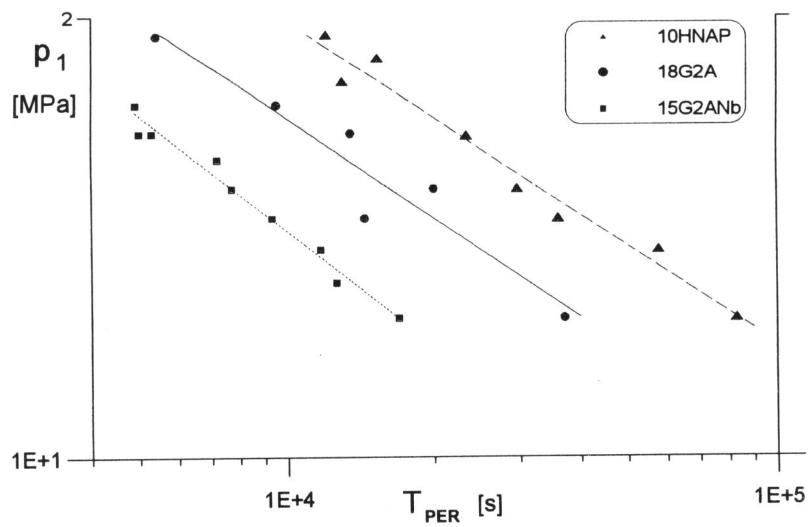

Fig.2.Results of cavitation tests for three steels.

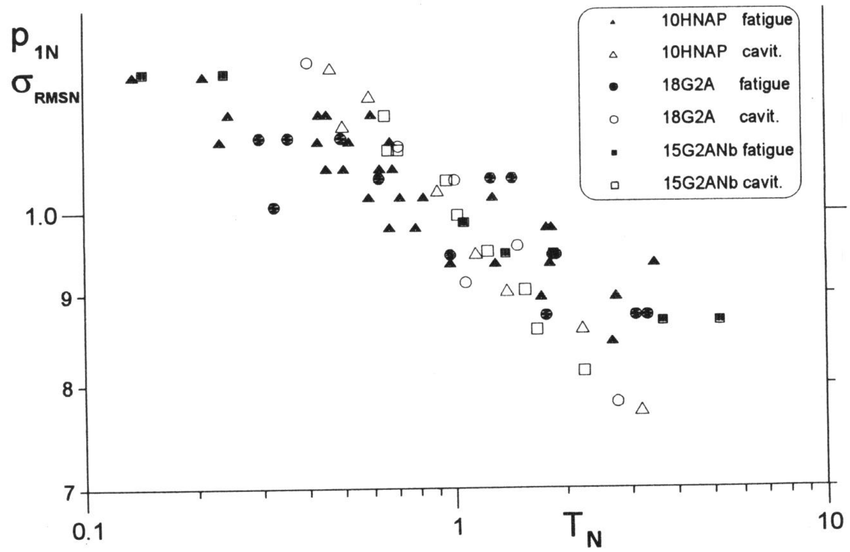

Fig.3.Comparison between fatigue and cavitation normalized results for three steels.