キャビテーション噴流式壊食試験方法の改訂について

Revision of Standard Test Method for Erosion of Solid Materials by Cavitating Jet

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In order to keep "standard test method for erosion of solid materials by cavitating liquid jet", i.e., ASTM G134 (1), inter laboratory study ILS was carried out by collaboration with four different institutions. Tested materials were aluminum, bronze, two types of nickel alloy and stainless steel. Mass loss curves were obtained at each institution by using cavitating jet apparatuses implemented in relation to ASTM G134, and maximum cumulative erosion rates were discussed. "Repeatability" coefficient of variation was from 2 % to 7 % and "Reproducibility" coefficient of variation was from 6 % to 22 %.

Key Words:　Cavitation, Erosion, Jet, Material test

1. Introduction

A standard test method for erosion of solid materials by a cavitating liquid jet was established in 1995, as ASTM G134 (1) by ASTM G02 committee. However, until now inter laboratory study was not carried out. In order to maintain ASTM G134, inter laboratory test was required.

Although there is standard test method for cavitation erosion using vibratory apparatus, i.e., ASTM G32 (2), hydraulic parameters such as cavitation number, pressure, flow velocity cannot be considered. When the cavitating jet is used for the material test to evaluate cavitation erosion resistance, effects of hydraulic parameters can be evaluated. Thus a test method using a cavitating jet was established based on Lichtarowicz's work (3),(4). And also, the testing time to get maximum cumulative erosion rate of ASTM G134 is much shorter than that of ASTM G32. It is worthwhile to maintain ASTM G134.

In order to carry out inter laboratory tests of ASTM G134, the erosion tests using a cavitating jet apparatus were carried out at four institutions using five materials.

2. Experimental Apparatus and Procedures

The erosion tests using cavitating jet apparatus were carried at Tohoku University, Nihon University, Fukui University and Dynaflow Inc. As erosion rate using the cavitating jet apparatus depends on the nozzle size and geometry (5), the standard size and geometry was used in the tests. As the erosion rate also depends on standoff distance, i.e., distance from nozzle to specimen surface, the optimum standoff distance, in which erosion rate has a maximum, is examined by using aluminum specimen, and then tested at optimum standoff distance. Each material was examined at three times at each institution.

The used materials were pure aluminum Japanese Industrial Standards JIS A1070B as soft metals, bronze JIS CAC402 which was used for typical materials of screws for ships, nickel 200 JIS NW2200 which was used in ASTM G32 and G134, popular nickel JIS NW2201 and stainless steel JIS SUS316L as rather hard materials. Tables 1 and 2 shows the mechanical

Table 1 Mechanical properties of tested materials

Materials	JIS	Yield strength MPa	Tensile strength MPa	Elongation %	Reduction of area %
Pure aluminum	A1070B	102	125	34.3	—
Bronze	CAC402	—	253	26	—
Nickel 200	NW2200	264	559	46.1	88.2
Nickel (low carbon)	NW2201	113	358	68	—
Stainless steel	SUS 316 L	389	594	53	76

Table 2 Chemical composition of tested materials (Mass %)

	C	Si	Mn	P	S	Cu	Ni	Fe	Cr	Mo	Al	Sn	Zn	Mg	Ti
A1070B		0.03	–			–		0.17			Bal		–	–	–
CAC402						87.20						8.17	4.12		
NW2200	0.106	0.13	0.14		0.0005	0.15	Bal	0.21							
NW2201	0.01	0.11	0.20		0.001	0.01	Bal	0.02							
SUS316L	0.012	0.19	1.62	0.034	0.015		12.02	Bal	16.74	2.01					

properties and chemical composition of tested materials. The used specimens were prepared at Tohoku University and delivered to the other institutions.

3. Results

Figure 1 reveals the mass loss Δm changing with time t for tested materials at each institution. Blue line, pink line, green

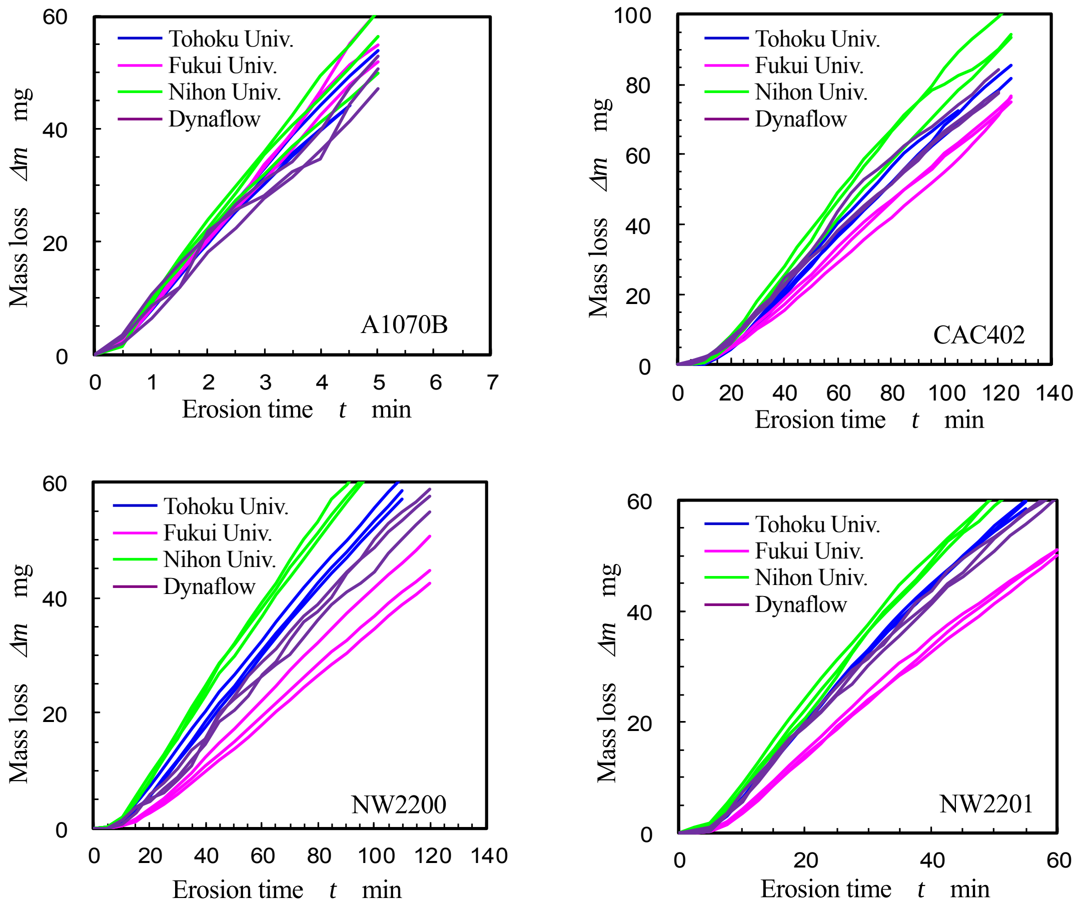

Fig. 1 Erosion curve of tested materials (continued)

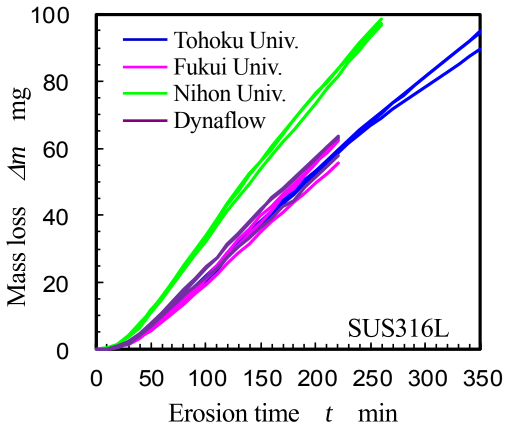

Fig. 1 Erosion curve of tested materials

Table 3 Summary of erosion test

		A1070	NW2201	CAC402	NW2200	SUS316L
Tohoku Univ.	Average	10.54	1.119	0.685	0.538	0.271
	Standard deviation	0.53	0.013	0.028	0.017	0.003
	Coefficient of variation %	5.1	1.2	4.0	3.2	0.9
Fukui Univ.	Average	11.45	0.858	0.608	0.383	0.274
	Standard deviation	0.81	0.024	0.007	0.035	0.019
	Coefficient of variation %	7.1	2.8	1.2	9.2	6.9
Nihon Univ.	Average	11.69	1.244	0.812	0.648	0.379
	Standard deviation	0.70	0.032	0.055	0.021	0.005
	Coefficient of variation %	6.0	2.6	6.7	3.2	1.4
Dynaflow	Average	10.32	1.077	0.691	0.484	0.280
	Standard deviation	0.95	0.034	0.072	0.023	0.015
	Coefficient of variation %	9.2	3.2	10.4	4.8	5.3
Average of laboratory averages		11.00	1.074	0.699	0.513	0.301
"Repeatability" standard deviation		0.75	0.026	0.040	0.024	0.010
"Reproducibility" standard deviation		0.67	0.161	0.084	0.111	0.053
"Repeatability" coefficient of variation %		6.8	2.4	5.8	4.7	3.5
"Reproducibility" coefficient of variation %		6.1	15.0	12.1	21.6	17.5

line and violet line show the results of Tohoku University, Fukui University, Nihon University and Dynaflow, respectively.

Table 3 shows the summary of results of erosion tests. “Average” of each institution means the average value of maximum cumulative erosion rate from three repeat tests at each institution. “Standard deviation” of each institution was the standard deviation of average value of the three repeat tests at each institution. “Coefficient of variation” was obtained from standard deviation divided by average. “Repeatability” means the average of standard deviation of each institution. “Reproducibility” was obtained from the standard deviation of average of each institution. "Repeatability" coefficient of variation and "Reproducibility" coefficient of variation were obtained from normalization of "Repeatability" standard deviation and "Reproducibility" standard deviation by average of laboratory averages, respectively. “Repeatability” coefficient of variation depends on the materials, and it was from about 2 % to 7 %. “Reproducibility” coefficient of variation was also changing with materials from 6 % to 22 %.

In order to examine the relative erosion rates obtained by each institution, Fig. 2 shows the maximum cumulative erosion rate normalized by the maximum cumulative erosion rate of CAC402 at each institution. For example, the relative erosion

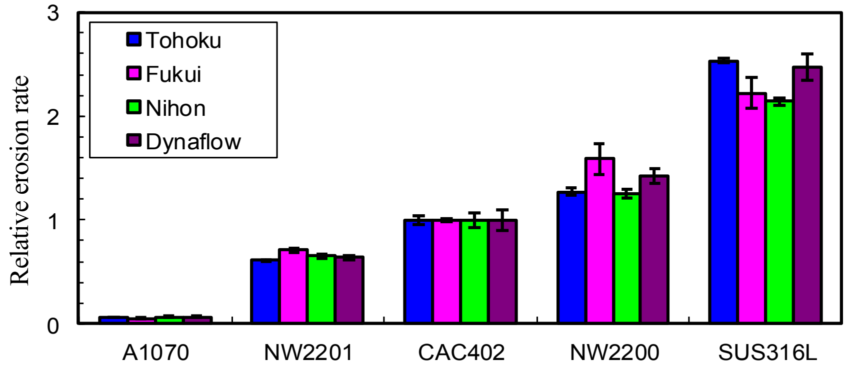

Fig. 2 Relative erosion rate normalized by erosion rate of CAC402

rates of SUS316L of each institution were as follows. Tohoku University was 2.53 ± 0.02, Fukui University was 2.22 ± 0.15, Nihon University was 2.14 ±0.03 and Dynaflow was 2.47 ± 0.13. As mentioned in the previous report [5], the relative erosion rates were very similar, even though the cavitation intensity was different.

4. Conclusions

In order to maintain ASTM G134, the erosion tests using the cavitating jet apparatus in conformity to ASTM G134, were carried out in four institutions using five materials and the maximum cumulative erosion rates were discussed. The coefficient of variation in each institute was about 1 % - 10 %. "Repeatability" coefficient of variation was 2 % - 7% and "Reproducibility" coefficient of variation was 6 % - 22 %.

References

(1) ASTM Standard, G134-95(2010), Standard test method for erosion of solid materials by a cavitating liquid jet, Annual book of ASTM standards, 2010.

(2) ASTM Standard, G32-10, Standard test method for cavitation erosion using vibratory apparatus, Annual book of ASTM standards, 2010.

(3) A. Lichtarowicz, Use of a simple cavitating nozzle for cavitation erosion testing and cutting, Nature Phys. Sci. 239 (1972) 63-64.

(4) A. Lichtarowicz, Cavitating jet apparatus for cavitation erosion testing, ASTM STP 669 (1979) 530-549.

(5) H. Soyama, Effect of nozzle geometry on a standard cavitation erosion test using a cavitating jet, Wear 297 (2013) 895-902.