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STATISTICAL ANALYSIS OF FRACTURE MECHANICS PARAMETERS OF LARGE STRUCTURES

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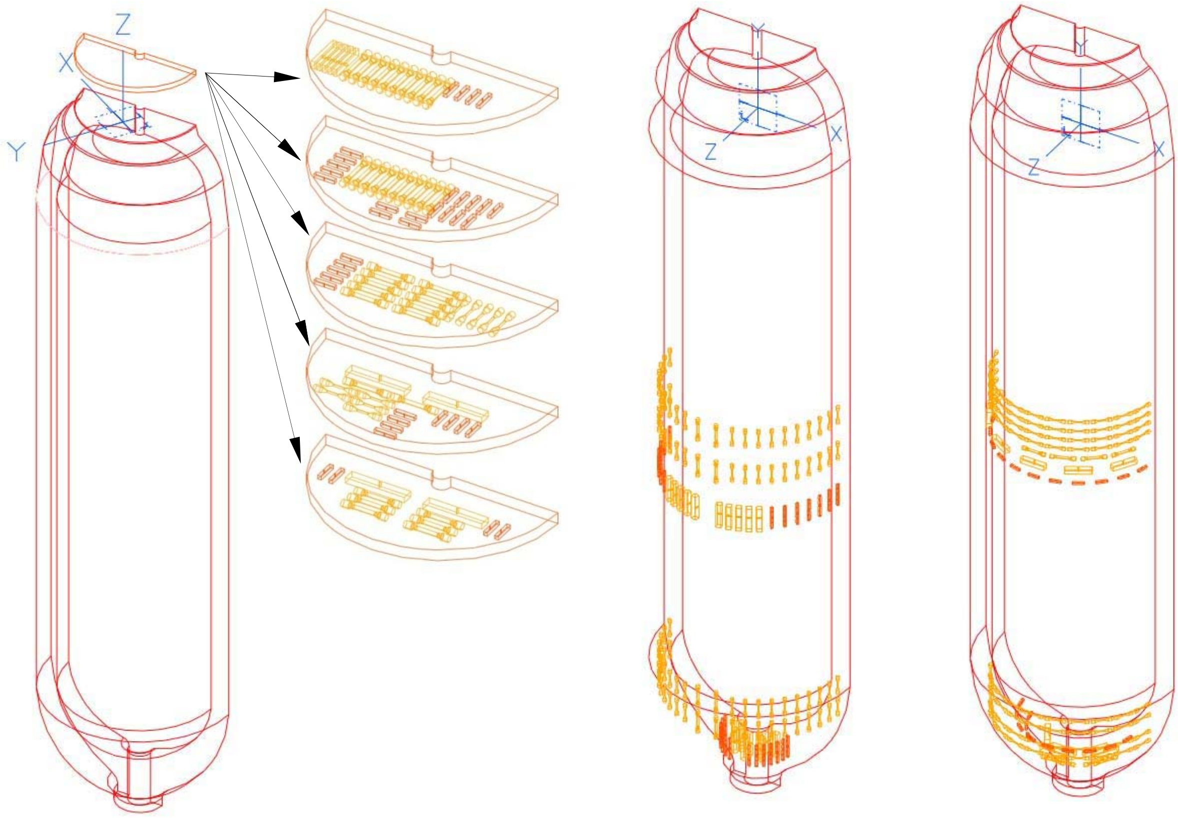
ABSTRACT
Results presented in this paper relate to a part of the complex mechanical testing. This paper in the form of preliminary notes presents results of fracture mechanics tests conducted in two laboratories on samples taken from various locations of thick-walled pressure vessels and from different directions in relation to the texture of the material. The main task of the statistical analysis presented in this paper is to determine deviation of results of fracture mechanics parameters and whether they are relevant for assessing the status of the pressure vessel.
Keywords: fracture mechanics, statistical analysis, thick pressure vessels.

1. INTRODUCTION
The aim of performing tests presented in this paper is to get a complete picture of mechanical properties of the pressure vessel material. Because of the way of making pressure vessels which is plastic deformation process, it can be a cause of increased results deviation, and in particular, because the details of production technology are not known. The process of taking samples for testing for these kind of structures means very often the destruction of the structure what is not always possible or is too expensive. If it is possible to take samples then the question is where to take the same, and whether the results of testing on these samples are relevant to the assessment of the state of the vessel. On the other hand, tests are carried out in two independent laboratories, which also can give some discrepancy between the results [3].

2. APPLIED RESEARCH METHODS
2.1. Location and dimensions of specimens
Analyzed pressure vessels are in use of many years, and were produced by plastic deformation as a single piece of steel quality 40Mn6[1]. Pressure vessels have the following dimensions: diameter outer Ø998 / inner Ø800 mm and a height of approx. 4000 mm, wall thickness of approx. 99 mm. Because of the size and a method of production there are certain discrepancies of presssure vessel dimensions, which do not affect the functionality.
Samples are taken from the middle part of the pressure vessels, from the dished end, and from the bottom of the vessel. Figure 1 shows all the samples for destructive testing (tension, impact, fatigue, crack growth rate and fracture mechanics). Tests were performed in two laboratories. Specimens used for fracture mechanics testing are of SEB type with different dimensions, data of test specimens and test results are given in Table 1.



a) Bottom plate - samples from two orthogonal directions *b) Middle and dished end – axial direction* *c) Middle and dished end – tang. direction*

Figure 1. Location and orientation of destructive testing samples

2.2. Testing procedure applied

In the Lab 1 all experiments were carried out by method of successive partial relief of single specimen, as defined by ASTM E1152 [4]. In Lab 2, determination of the critical value of J-integral and critical crack tip opening CTOD was performed according to ASTM E1820 [5]. Because the requirements of the plane strain condition:

$$B \geq 2{,}5 \cdot \left(\frac{K_{Ic}}{R_{eH}} \right)^2 \quad \dots(1)$$

are not achieved, rather than applying linear elastic fracture mechanics, elastic-plastic fracture mechanics is applied, also defined by ASTM E1820 [5]. The goal of using elastic-plastic fracture mechanics is that the value of the critical stress intensity factor, K_{IC}, to be determined indirectly via critical J integral, J_{IC},:

$$K_{Ic} = \sqrt{\frac{J_{Ic} \cdot E}{1 - \nu^2}} \ . \quad \dots(2)$$

By applying the basic formula of fracture mechanics and entering the value of material yield strength, $\sigma_{max} = R_{eH}$, assuming a factor of Y = 1.12 approximate values for critical crack length, a_c, were calculated according to the model:

$$a_c = \frac{1}{\pi} \left(\frac{K_{Ic}}{Y \cdot \sigma_{max}} \right)^2 \ . \quad \dots(3)$$

2.3. Testing results

The subject of analysis are critical crack lengths, which are determined with using the form (3). Data on samples and test results are given in Table 1 [2]. Using the software Statistica 10, and the module "t-test dependent samples", an analysis of the test results is given in Table 1, and results of t-test are given in Table 2.

Table 1. Specimen data and results of testing

No.	**Sample location and dimensions, mm**		**Yield Stress R_{eH}, MPa**	**Stress intes. factor K_{Ic}, MPa√m**	**Critic. lenght a_c, mm**	**Lab.**	**No.**	**Sample location and dimensions, mm**		**Yield Stress R_{eH}, MPa**	**Stress intes. factor K_{Ic}, MPa√m**	**Critic. lenght a_c, mm**	**Lab.**
1	S	12x25x125	343,5	133,8	48,3	Lab 1	20	B	15x30x160	328,7	129,2	53,6	Lab 1
2	S	12x25x125	343,5	137,9	51,3	Lab 1	21	B	15x30x160	328,7	94,3	28,5	Lab 1
3	S	12x25x125	343,5	140,6	53,4	Lab 1	22	B	15x30x160	328,7	81,3	21,2	Lab 1
4	S	12x25x125	343,5	138,5	51,8	Lab 1	23	B	10x20x100	328,5	57,8	9,9	Lab 1
5	S	12x25x125	343,5	118,2	37,7	Lab 1	24	B	10x20x100	328,5	81,1	19,8	Lab 1
6	S	12x25x125	343,5	138,5	51,8	Lab 1	25	B	10x20x100	328,5	81,4	19,6	Lab 1
7	D	12x25x125	319,5	128,8	51,8	Lab 1	26	B	15x30x160	327,8	91,5	24,7	Lab 1
8	D	12x25x125	319,5	120,2	45,1	Lab 1	27	B	15x30x160	327,8	80,8	19,3	Lab 1
9	D	12x25x125	319,5	132,2	54,5	Lab 1	28	B	15x30x160	327,8	91,3	24,6	Lab 1
10	D	12x25x125	319,5	136,9	58,5	Lab 1	29	S	25x25x125	343,5	246,7	131	Lab 2
11	D	12x25x125	319,5	142,2	63,1	Lab 1	30	S	25x25x125	343,5	175,5	66,3	Lab 2
12	D	12x25x125	319,5	139,9	61,1	Lab 1	31	S	25x25x125	343,5	196,1	82,8	Lab 2
13	D	12x25x125	319,5	145,4	66,0	Lab 1	32	S	25x25x125	331,5	158,9	58,4	Lab 2
14	D	12x25x125	319,5	136,5	58,1	Lab 1	33	S	25x25x125	331,5	178,7	73,8	Lab 2
15	D	12x25x125	319,5	143,7	64,4	Lab 1	34	S	25x25x125	331,5	143,5	47,6	Lab 2
16	D	12x25x125	319,5	136,7	58,3	Lab 1	35	D	25x25x125	325	158,9	60,7	Lab 2
17	B	10x20x100	292,6	81,3	23,4	Lab 1	36	D	25x25x125	325	100,7	24,4	Lab 2
18	B	10x20x100	292,6	100,6	35,8	Lab 1	37	D	25x25x125	325	121,3	35,4	Lab 2
19	B	10x20x100	292,6	98,3	34,2	Lab 1	-	-	-	-	-	-	-

Legende: M-middle(cilindrical part) of vessel, D-dish end of vessel, B-bottom plate

Table 2. T-test for Dependent Samples of Lab 1 i Lab2

	Marked differences are significant at $p < 0,05$									
Variable	Mean	Stand. devia.	N	Diff.	Std. dev. Diff.	t-value	df	p	Confidence -95,000%	Confidence +95,000%
Lab 1	49,522	5,236								
Lab 2	64,488	30,90	9	-14,966	31,917	-1,4067	8	0,197	-39,500	9,566

df – degrees of freedom, df = N-1.
p – level of significance, or fault after we claim that there was a statistically significant change.

Table 2 shows that the value of p = 0,197134 > 0,05, which does not achieve the requirements of hypotheses which claim that the error deviation of results between two variables is significant. It can be concluded there is no statistically significant difference in results of the two laboratories, and test results can be taken into account and considered as a single set. The measurement results can be presented as shown in Figure 2, Figure 3 and Figure 4. Distribution of results in a given set (sample representing a given phenomenon or size) can be asymmetric (deformed) or symmetric (non-deformed).

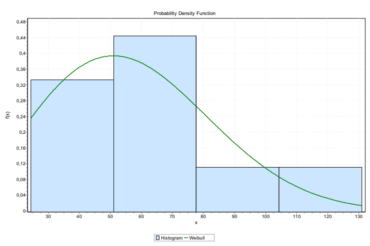


Figure 2. Distribution of samples measured in Lab 1

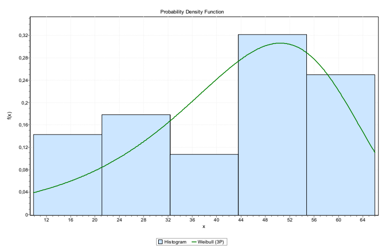


Figure 3. Distribution of samples measured in Lab 2

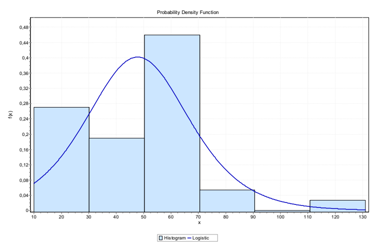


Figure 4. Distribution of integrated results from Lab 1 and Lab2

Figure 2 shows the case of unsymmetrical distribution or positively distorted distribution - right side, and Figure 3 shows also unsymmetrical distribution or negatively distorted distribution - left side. Measurements in both cases reflecting the asymmetric distribution and for repairing of deformed distribution it is necessary to increase the number of samples.

According to the fact that results of "t-test" showed no significant difference between results from two comparative laboratories, with consolidation of measurement results of critical crack length increases the number of samples and thus a symmetrical (non-deformed) distribution appears as shown in Figure 4.

An analysis of results of samples taken from various locations on the vessel is shown in Table 3.

Table 3. T-test for Dependent Samples taken from different locations

	Marked differences are significant at p < 0,05									
Variable	Mean	Stand. devia.	N	Diff.	Std. dev. Diff.	t-value	df	p	Confidence -95,000%	Confidence +95,000%
M	62,85	24,74								
D	55,5	11,35	12	7,35	22,409	1,1365	11	0,279	-6,884	21,584
D	55,500	11,358								
B	26,216	11,068	12	29,283	17,30	5,8635	11	0,000109	18,291	40,275
M	62,85	24,74								
B	26,216	11,068	12	36,6333	32,4818	3,9068	11	0,002448	15,995	57,271

Table 3 shows that the differences between samples taken from the middle(M) and bottom(B), and also from the dished end(D) and bottom(B), are unacceptable, i.e. they are not from the same set, while test results of samples from the middle(M) and the dished end(D) can be analyzed as belonging to the same set.

3. CONCLUSIONS

Presented results demonstrate that in the analysis of structures of large dimensions there is a need to take care about the place of sampling, the number of samples for the laboratory tests and the laboratories in which tests are performed. It is clear that in this case deviations of most results are acceptable, but also if ther is a small number of samples deviation of min. and max. values can be significant and lead to completely wrong conclusions. A significant variation was observed in samples taken from the bottom of vessels and will be subject of further analysis.
It is particularly interesting that the only place where it is possible to take samples, without destroying structure, the bottom of the pressure vessel. A possible cause of this difference of results is a manufacturing technology of pressure vessel, i.e. the texture of the material.

4. REFERENCES

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