Journal of POLISH CIMAC
Faculty of Ocean Engineering & Ship Technology
GDAŃSK UNIVERSITY OF TECHNOLOGY

THE PROBLEM OF ASSESSMENT OF INITIAL POINT OF CRACK DEVELOPMENT IN IMPACT BENDING TEST

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Abstract

The problem of assessment of the initial point of a crack in in static tests is already recognizable and simple to determine. On the basis of this point the force F_p and energy E_p necessary to initialize fracture, thus due to these parameters it is possible to determine parameters of crack resistance. In case of dynamic loads, especially during the impact bending test of material samples, this problem is much more difficult and at the present level of science it is still current matter. In the article, in compliance with own research, the comparison of different methods of initial point determination in bend-test was performed, which is: compliance change of the sample, strain gauge tests (tensometric), mathematical processing of registered actions F(t), method of maximum force F_{max} with the most accurate method (pattern method): crack alteration, for tested steels 18G2A and St3S and aluminium alloy Ak12, in order to demonstrate essential differences in assessment of initial point of crack in impact bending test.

1. Introduction

The recognition of physical phenomena happening during the test of dynamic bending in tested samples, mainly for determination of force initializing cracking F_p, and energy necessary to initialize cracking E_p,, at this level is still subject to research. Precise denotation of cracking initial point enables for correct calculation of parameters of dynamic crack resistance such as:

- dynamic critical ratio of tension intensity K_{Id} [6, 7, 14]

$$K_{Id} = \frac{F_p \cdot S}{B \cdot W^{3/2}} \cdot f\left(a / w\right), \tag{1}$$

where:

F_p - force subtending a beginning of crack initialization, N
S - distance between props, mm
B - thickness of tested sample, mm
W - Width of sample, mm
a - length of fracture in sample, mm
f (a/w) - function of interspace shape in a sample.

- dynamic integral J_{Id} [6, 7, 14]:

$$J_{Id} = \frac{2E_p}{B\left(W - a\right)}, \tag{2}$$

where:

E_p - energy subtending initialization of crack, J
B - thickness of sample, mm
W - width of sample. mm
a - distance of interspace in sample, mm.

Pursuant to calculated parameters it is possible to assess other measurements such as: critical dynamic extension of crack – CODR, dynamic module of tearing of tested sample T_{mat} or critical size of defect a_d, in conditions of dynamic loads. Determined parameters are very important machining constants applied in engineering calculations of constructions working with impact loads.

Although determination of force (energy) initializing the beginning of material crack in conditions of static load is generally simple and obvious [1], in case of dynamic loads it is a problem, especially for ductile materials - as a result new methods of testing should be invented.

Recently, numerous different approaches are observed about the problem of assessment of initial crack point in condition of dynamic loads. This fact encouraged the author of the article to present the current level of knowledge on the topic and to share his own test results.

According to the suggestion of ruling ASTM norms [2], SEP1315[3] or ISO14556[4] and ESIS[5], the point of beginning of crack initiation is the point of maximum force F_m, determined on the basis of the diagram force-displacement, obtained from dynamic bending test.

Other authors of works [6,7] point out that this can be force located almost in the middle between dynamic force on yield limit F_{gy} and maximum force $F_{m.}$

Authors of publications [8,9], on the basis of mathematical processing of removed patterns P = f(f) or P = f(t) in test of impact bending, by usage of program FRACDYNA[9], assessed the initial point of crack, applying static processing of registered patterns by methods: differentiation, approximation, panning and joining of obtained high-frequency patterns.

On the contrary, the authors of research [10,11] in order to determine the point of crack initialization, they applied a wavelet analysis of magnetic signal, obtained from sensors situated on the beater of the impact drill. They showed its accuracy in contrast to the testing method of compliance change of bended sample (CCRM) and method of maximum force Fm.

In publications [12,13] authors applied the method of magnetic emission (ME) to determine the point of crack initiation and testing with application of strain gauge. (PD).

Authors of publications [14,15] used the method suggested by T. Tseng and T. Kobayasi, which is the method of compliance change of a sample [6,7] the assessments of crack initial point.

Described methods at the current level of science are very accurate but they require very sophisticated equipment and complex test methodology as well as advanced software in order to process patterns removed during impact test.

The exception may be the method of compliance change of the sample (CCRM), which is not time-consuming and a result can be obtained from one sample.

Described controversies of presented methods probably discourage the authors publishing standard norms, which would be the ruling norms in the future to assess mentioned parameters of dynamic crack resistance.

2. Own experiments

The author of this publication decided to commence comparison testing of the assessment of crack initiation point in selected materials: steels 18G2A and St3S as well as the alloy of aluminium AK12, applying different testing techniques. Very accurate method was used and accepted as a pattern method: alteration of crack and strain gauge measurement method, both of them were then compared to other methods: change of compliance of a sample, diagram static proceeding and method of maximum force.

The tests were performed on equipped impact hammer Psd300 with application of FRACDYNA [9] to formulate the results.

Fig. 1 presents methods of proceedings in assessment of cracking initial point, for evaluation of force F_p initializing cracking by multi-sample method (crack alteration), admitted as a pattern method for tested materials.

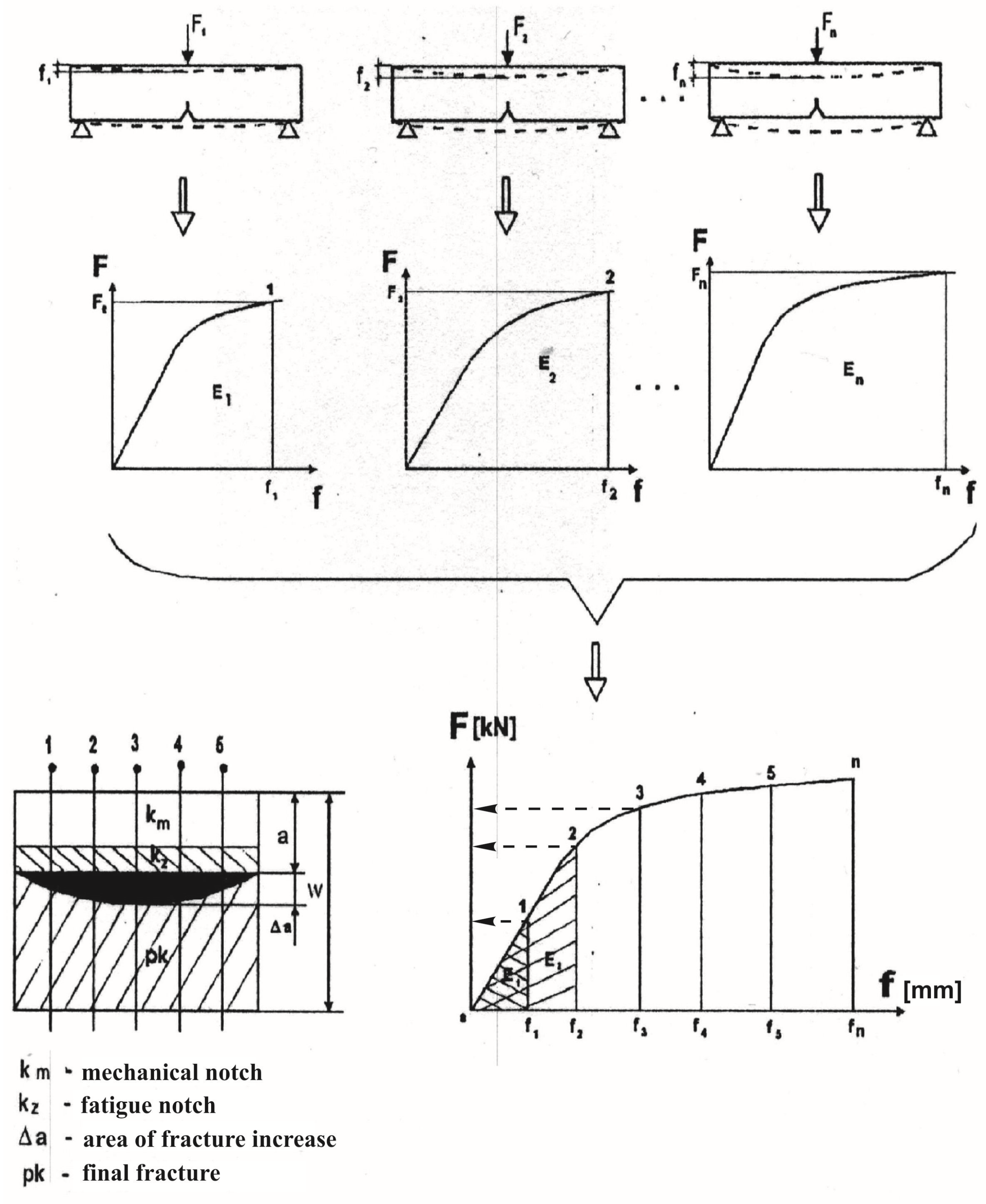

Fig. 1. Methodology of determination of cracking initiation point (force initializing cracking F_p) by method of crack alteration

For each of tested materials 10-15 impact samples were used, each with implemented endurance fracture with equal a/W = 0,45-0,55 [2].

According to fig. 1, increasing impact force F was causing stable increase of fracture by Δa in tested samples. In aim to obtain different values in fracture increase Δa with different load force, the instrument limiting knife movement of the pendulum was installed at the base of impact hammer. The scheme of this instrument is shown in the fig. 2.

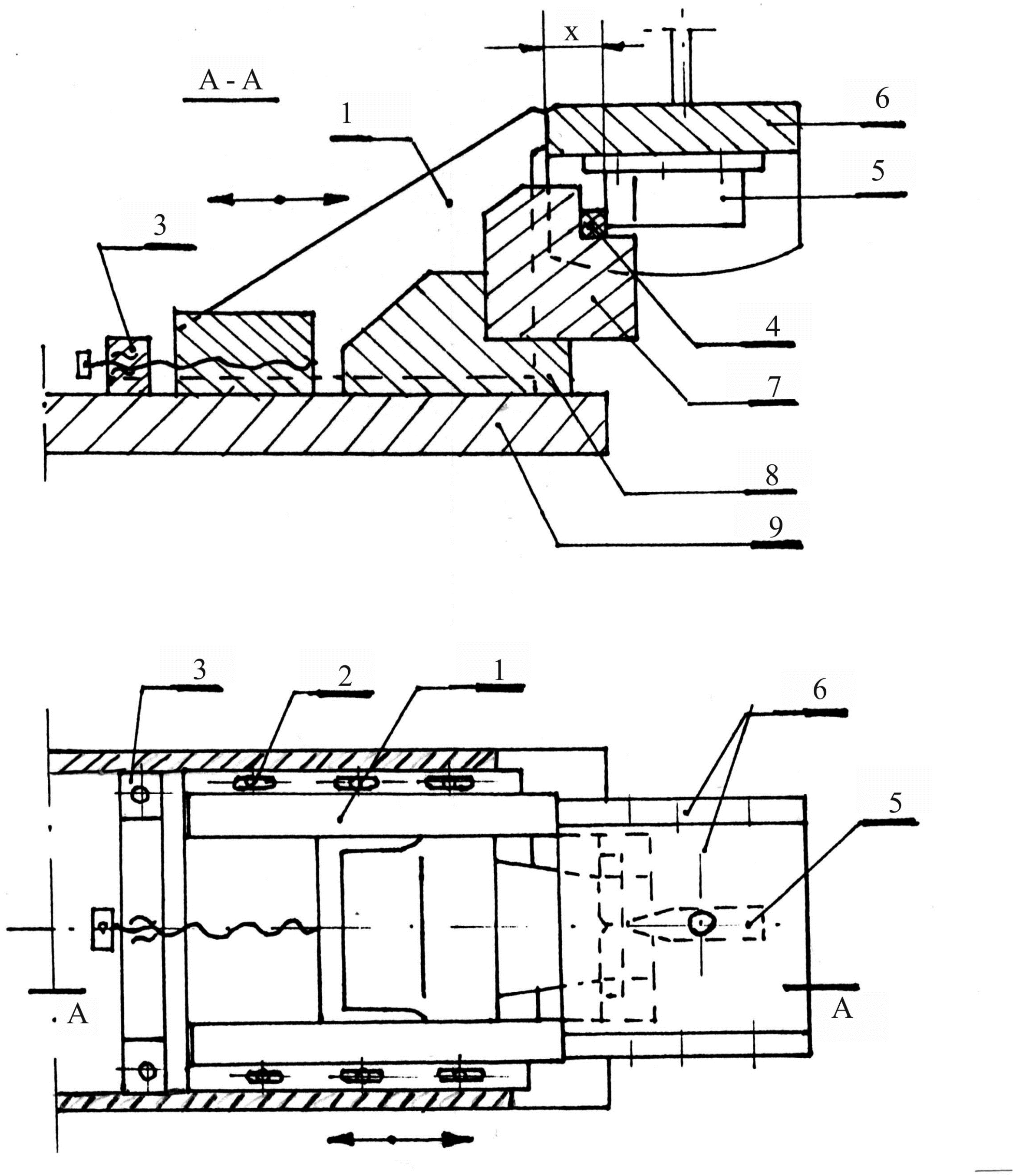

Fig. 2. The instrument limiting the impact force of the pendulum knife of a impact hammer: 1 – mobile resistance platform, 2- platform block, 3 – support pole with micrometer screw, 4 – tested sample, 5 – pendulum knife of impact hammer, 6 – integument of knife, 7 – support coil, integument of support coil, 9 – base of impact hammer

This machine due to function of regulation of the distances X of resistance surfaces of mobile platform from the impact surface of the pendulum knife enabled obtaining different values of fracture increase Δa of tested samples and completely disabled the destruction of the sample (crack alteration).

During each test the steps of load F(t) were recorded on impact hammer as well as the progress of displacement f(t) in the time function. An example of such diagram for alloy of aluminium AK12 is shown in the fig. 3.

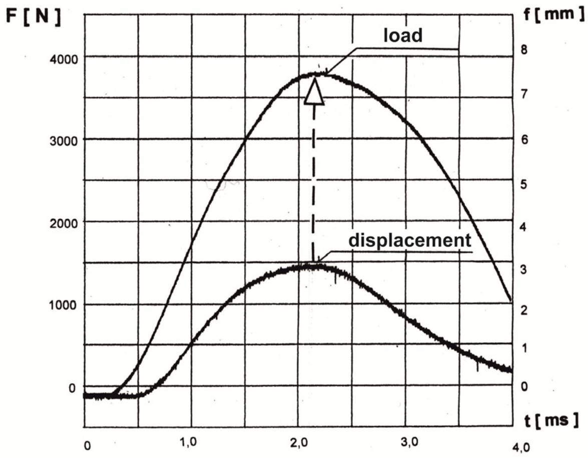

Fig. 3. Example diagram of load F and displacement f in time function t for AK12 alloy

Obtained diagrams were further transformed into investigation of function F(f), which enabled to calculate the energy used by particular samples loaded with different forces.

In order to identify the extension of increasing crack Δa in case of each force, the samples were subject to oxidation in temperature 350°C for 15 minutes in laboratory furnace, then they were cooled and further cracked on impact hammer. On the surfaces of a crack the fracture increase area Δa painted with blue color was measured, easily recognizable in comparison with inserted endurance crack. Measures was taken from 5 points (fig. 1 on the left side), located along the forehead of endurance crack. Thus, value Δa from one sample was treated as an arithmetic average for particular measurements on the surface of crack increase area. By this method it was possible to exactly assess the force F_p initializing cracking and count corresponding energy E_p, which referred to the lowest of obtained crack increases Δa (the beginning of of crack). As an example in the fig. 4a there were shown photographies of sample fracture surfaces after dynamic load with different crack increases Δa for the steel 18G2A.

In the fig. 4b the forces while altered cracks, implemented to the diagram of impact bending of this steel, referring to tested samples from N1 to N6, and the force initializing crack F_p was referred to N1.

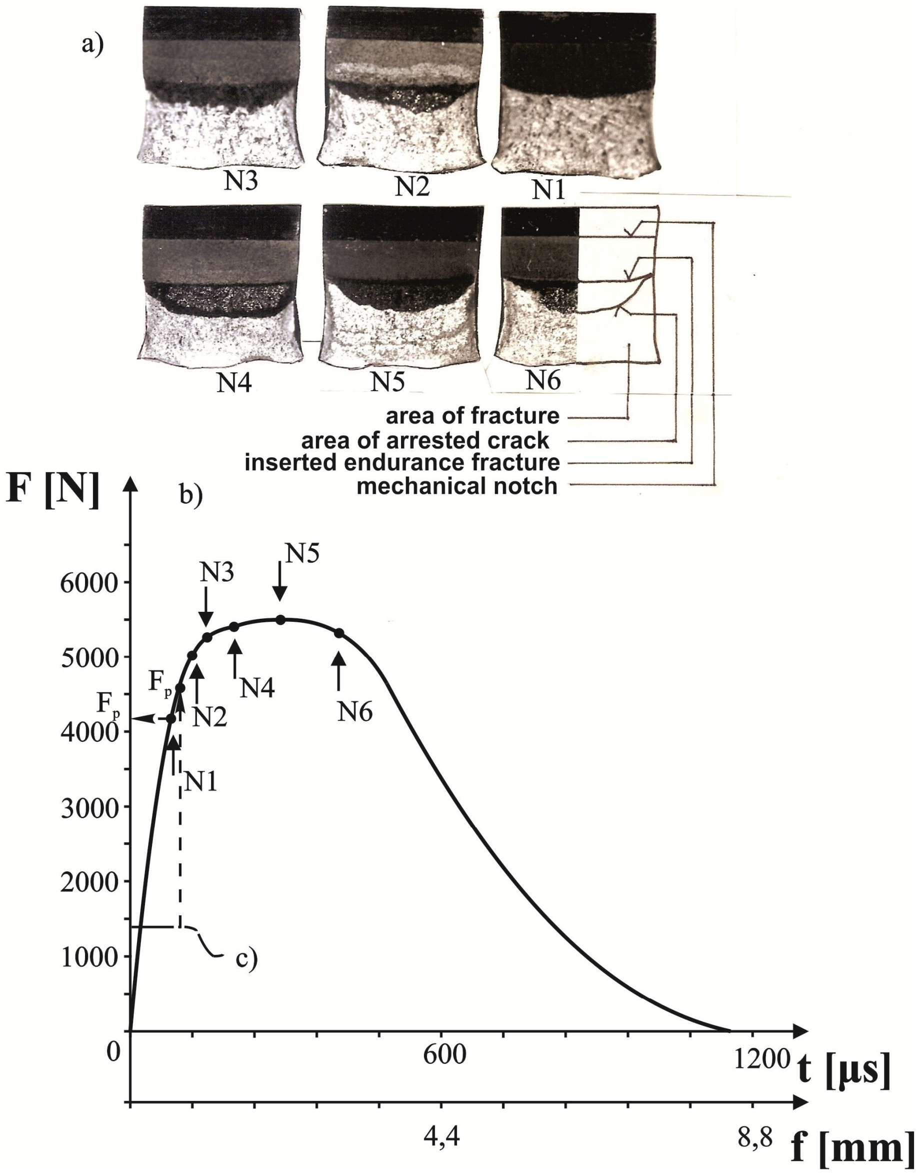

Fig. 4. Photographies of sample fracture surfaces after dynamic load with different crack increases, obtained by the multi-sample method of tested steel 18G2A (a), points referring to particular crack increases for these samples, inserted on the diagram of dynamic destruction of this steel (b), recorded sign after peeling tensometric sensor out, determining force Fp in strain gauge test (c)

In the pictures visible are: area of altered fracture increase Δa , of inserted endurance fracture, area of mechanical notch and fracture of tested samples.

Determination of crack initiation point by tensometric tests is done by tensometer strips on the end of a crack of inserted endurance fracture. The tensometers strips LY58 by Hottinger Baldwin Messtechnik were used, which were further connected in parallel to the force sensor and the sensor of displacement of impact hammer. This method enabled for record of the moment of crack of a sample. Due to this result the force corresponding with the moment of sensor destruction could be determined. The point describing this moment was accepted as the beginning of crack determining the force initializing the cracking F_p. It was demonstrated on fig. 4c regarding the steel 18G2A.

The method of assessment of the beginning of crack by a method of compliance change $\Delta C/C$ was performed in the following way: The dependence on the recorded deviation F(f) was described:

$$\Delta C / C = \left(C - C_e \right) / C_e , \tag{3}$$

where:

$\Delta C/C$ – relative compliance change

C – compliance determined along the deviation F(f), $C = \frac{f}{F}$

C_e – elastic compliance described for linear-elastic part of a deviation F(f), $C_e = \frac{f_e}{F_e}$.

On the basis of the analysis of the curve $\Delta C/C$ shape with substantial change of its position while cracking, the point of crack initiation was determined , then due to this point the force F_p and energy E_p (standing for the start of crack) were determined. The scheme of this method is presented below on the fig. 5.

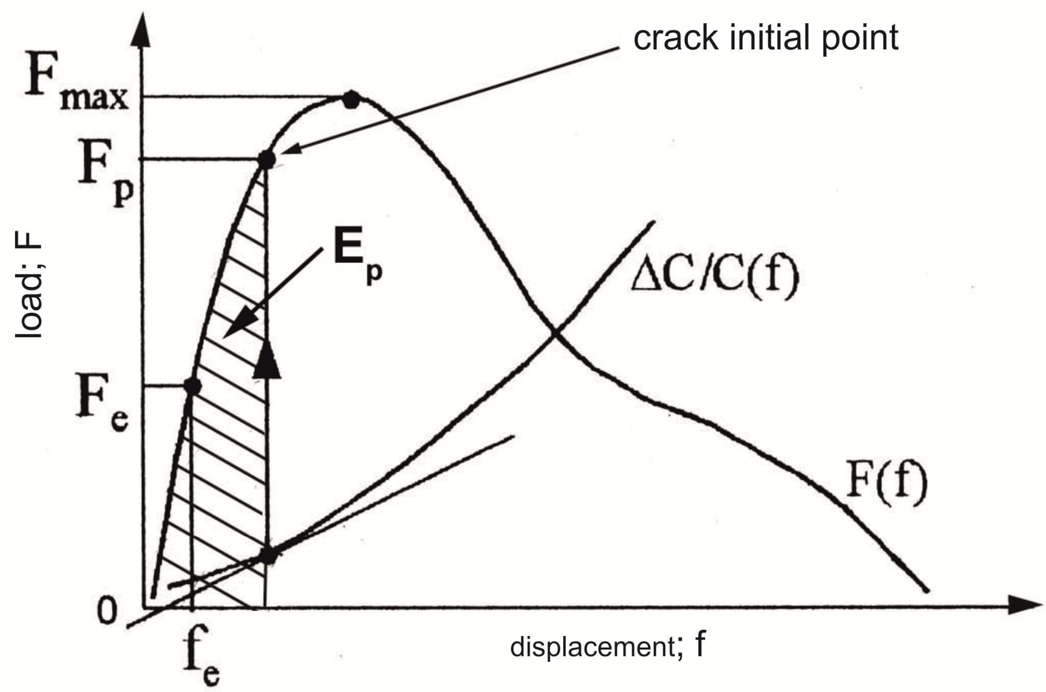

Fig. 5. Scheme of determination of crack initial point by method of compliance change of a sample

The designation of the crack initial point with methods of mathematical processing of recorded deviations during the test of impact bending F(f) or F(t) was performed using already mentioned program FRACDYNA [9], especially the modules 1, 2, 3 and 4 (fig. 6) were applied, with accordance to [8, 9], which enabled to outline the point of initiation of crack and the force initializing crack F_p on the basis of the mathematical analysis.

The force initializing crack in the method of maximum force was applied that F_p is the force F_{max} which is obtained on the recorded deviation by tested sample (point 6, fig. 7).

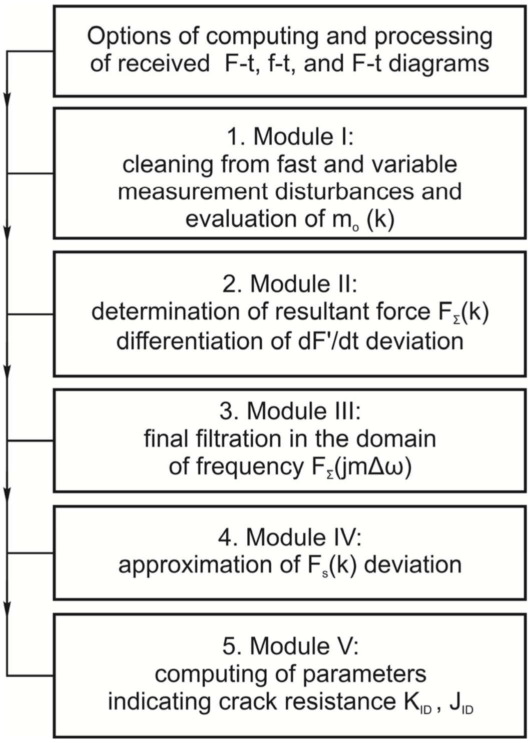

Fig. 6. Adjusted calculation options for determination of crack initial point by mathematical methods of recorded actions F(f) and F(t) by program FRACDYNA

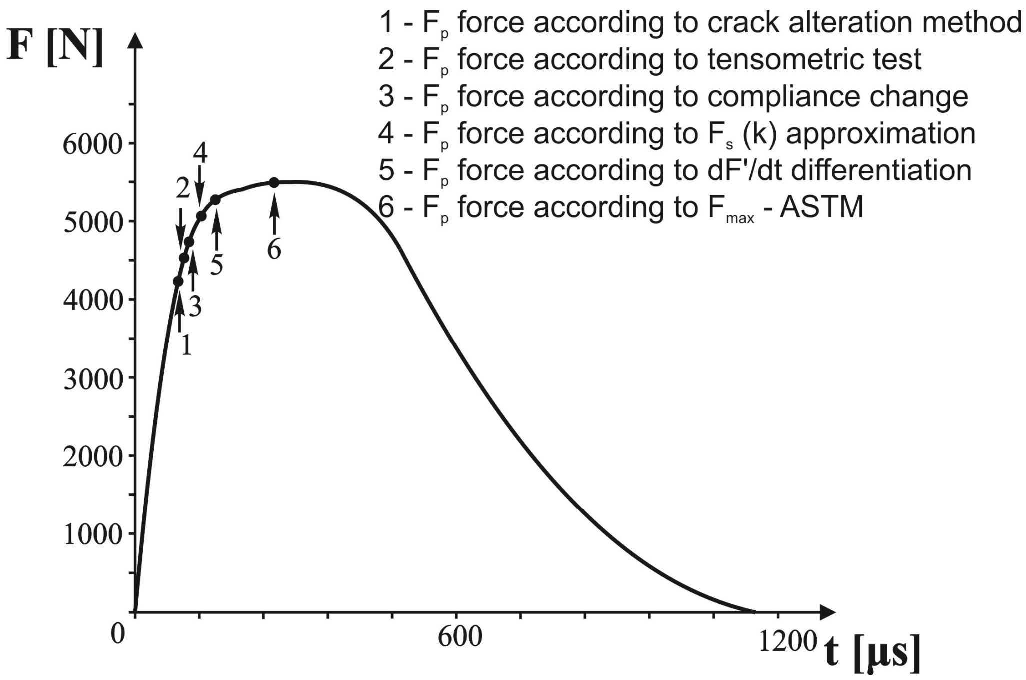

Fig. 7. Assessment of the force point of initial crack F_p by various methods for tested steel 18G2A

On the image 7 the diagram load-to-time was presented for the tested steel 18G2A (averaged for M=61 steps), on which the points of initial crack obtained by various methods were inserted and in the table 1 the specific values of F_p were included, concerning different methods of proceeding.

Tab. 1. Value of forces of crack initiation start point F_p in [N], obtained by various methods for tested materials

Tested material	Test method					
	Crack alteration (1)	Tensom. test (2)	Compliance modification (3)	Deviation approximate (4)	Differentiation of deviation (5)	Forces F maximum (6)
18G2A	4276	4512	4685	5102	5269	5389
St3S	3144	3215	3412	3808	3941	4272
AK12	2953	2814	3009	3425	3667	3794

Table 2 presents percentage differences of modifications of particular methods in comparison with accurate methods: pattern method (1) and tensometric tests (2).

Tab. 2. The differences in percentage modifications in particular methods of determining the crack initial point of tested materials (designation of methods as in table 1 and image 1)

Tested material	Percentage diffreences [%]								
	(1)/(2)	(1)/(3)	(1)/(4)	(1)/(5)	(1)/(6)	(2)/(3)	(2)/(4)	(2)/(5)	(2)/(6)
18G2A	5.52	9.56	19.32	23.22	26.91	2.44	13.08	16.78	19.44
St3S	2.26	8.52	21.12	25.35	35.88	6.13	18.45	22.58	32.88
AK12	-4.71	1.91	15.98	24.18	28.38	6.92	21.71	30.31	34.71

Pursuant to presented results it can be stated that taking into consideration the most accurate testing method which is the method of crack alteration (many samples) and method of tensometric measurements, the method of compliance modification for force initializing crack F_p assessment is the closest to described methods. The differences are minimal and they estimate 8-10%, which weighs in favour of method of compliance modification as the most accurate way in comparison with pattern method (alteration of crack).

3. Conclusion

With support of obtained results of tests it can be implied on current level of knowledge, that in further discussions and changes of norms, the method of compliance modification of impact bended sample should act officially as a pattern method (primary) to determine the point of crack initiation and assessment the dynamic parameters of resistance for crack, especially for materials ductile and elastic.

It is a method universal and uncomplicated at the same time, the result can be obtained from the test of one sample, it is also possible to apply in industrial conditions. The results of crack initial point test by this method slightly differ from the results obtained in pattern method, but more complicated, it is a method of crack alteration (about 2 – 8%).

Such a small value of differences in results can be completely accepted with concerning other methods being time-consuming, complex and expensive.

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