Application of a Structural Integrity Assessment Software

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ABSTRACT

In this paper, a brief overview is given of two projects concerning structural integrity assessment, including on-line software based on SINTAP procedure. An example of the software usage is presented, and the obtained results are compared with the experimental data and discussed.

Keywords: Structural Integrity Assessment, Welded Joint, Crack Initiation, Fracture Initiation

INTRODUCTION

Fracture mechanics, having in mind its theoretical and experimental techniques [1, 2], is a good basis for reliable structural integrity assessment procedures. There are several such procedures, and they are already being used for many materials; however, they can still be improved and adjusted, to achieve better efficiency and lower costs of design, construction and maintenance. The approach used for SINTAP (Structural integrity assessment procedure) [3] offers a very good basis for software solution, one of which is developed through MOSTIS (Mobile structural integrity assessment system) project [4], as a segment of a structural integrity assessment system. Four standard assessment levels of SINTAP procedure (0, 1, 2 and 3) are used, ranging from simple but conservative approaches where data availability is limited, to more accurate and complex approaches. A very important issue is assessment of structures comprised of more than one material - welded joints. The results can be presented as crack driving force (CDF) or failure assessment diagrams (FAD). The crack driving force (for example, the applied J-integral) can be plotted as a function of flaw size for different applied loads, or as a function of load for different flaw sizes and compared to the material's resistance to fracture. In a FAD, an assessment is represented by a point or a curve on a diagram and failure judged by the position of the point or curve relative to a failure assessment line. The result of this procedure is information whether the actual or postulated flaw will cause failure of the structure or it is possible to continue with its exploitation. The main principle is that failure occurs if the applied crack driving force exceeds the material's fracture resistance. Another step in the development of assessment procedures was made through FITNET project [5], which included fatigue, corrosion and creep modules, in addition to the fracture procedures included in SINTAP.

BACKGROUND

The purpose of structural integrity assessment is to determine the significance, in terms of fracture and plastic collapse, of flaws present in metallic structures and components. Loading or flaw dimensions can be varied, in order to check the possible increase of loading and/or flaw size that will lead to failure. It is important to note that this approach is not intended to supersede existing methods, but to serve together with them throughout the lifetime of a structure. It can be used for assessing in the design phase - in order to specify the material properties, design stresses, inspection procedures/intervals and acceptance criteria. It can also be used for fitness-for-purpose assessment during the fabrication, with respect to applied fabrication standards. During the operation phase, it can be used to decide whether continued use of a structure or component is safe (i.e. it is safe to continue operation until a repair can be carried out in a controlled manner), despite detected flaws or modified service conditions.

Having in mind that analytical and other methods used for the creation of SINTAP/FITNET procedure (and therefore also the software which is part of MOSTIS system) can give an estimate of the state of the structure, but cannot provide some more detailed information (e.g. stress or strain data at some important location in the structure), a new system - OLMOST (On-line monitoring of structures and fatigue) [6] is currently being developed. It is an integrated hardware and software solution for on-line and on-site measurement of structure state during its service life, in order to prevent failures due to flaws and inappropriate design. Configured as an expert system for on-line monitoring and automatic analysis of measured data, including automatic warning signals to supervisor, it is based on a data bank of materials and stress-strain behavior of components.

Strain state of the structure will be assessed by optical stereometric measurement of surface in critical spots, and/or some other measurement methodologies, depending on the construction type, operating conditions, safety requirements, etc. Having in mind that faults may change the behavior of structure, changes of the structure state can be used to indicate some flaws and anomalies which can not be measured directly. Wherever possible, wireless measurement will be applied; sensors will be wirelessly connected to the processor unit, and the signals will be assembled in mobile computer device. This device can be connected to the internet via GSM mobile network, and then to the server with master program for fault identification. In case of overloading or missing input parameters it will provide different warning signals, depending on the measured data.

Stress-strain behavior of the structure or some of its components will be assessed by numerical - finite element (FE) modeling. Comparison between numerical results and measured strains (or other appropriate quantities) provide relevant information concerning the stress state of the component and loading. The results for critical component in regular service will be used to establish an acceptable loading window. If the deformation state does not fall into this window, the expert system is going to provide decision to safe shut-down or stop the use of structure.

The reliable estimation of flaw size and its position in the component can be made by comparing the measured deformation behavior with the results of the numerical model with assumed size and position of the flaw. Another important usage of this new system is retrieving the loading history and assessment of cumulative damages occurring during the service life of the structure. The main purpose is on-site failure assessment analysis and estimating the remaining lifetime of damaged structure, to improve repair planning and optimize the component life cycle, with a possibility to provide appropriate commands to control the equipment.

APPLIED PROCEDURE

An example for assessment procedure using MOSTIS software is presented on a welded single-edge notched bend (SENB) specimen. The base metal (BM) is high-strength low-alloyed (HSLA) steel NIOMOL 490. Fatigue pre-crack is located in the weld metal (WM), along the axis of symmetry of the joint (one half of the specimen is shown in Fig. 1). Properties of the base metal and weld metal are given in Table 1. It can be seen from these data that the analysed joint is overmatched, having in mind that the mismatch ratio (ratio of the yield strength of the weld metal and the base metal) is larger than 1. As already mentioned, SINTAP/FITNET procedures can take into account this difference of material properties across the welded joint.

The behaviour of the joint under external loading is analysed using level 2 SINTAP procedure, and the results are presented in FAD diagram (Fig. 2). This diagram represents the change of the structure state during the increase of loading (straight line) and the critical state of the structure (failure assessment line). The value K_r, ordinate of the diagram, represents the ratio of the applied stress intensity factor K_I and the critical stress intensity factor K_{Ic}. The abscise L_r is the ratio of the applied loading and the plastic limit load of the structure.

Table 1 Properties of the materials

	WM	BM
E [GPa]	183.8	202.9
$R_{p0.2}$ [MPa]	648	545
R_m [MPa]	744	648

RESULTS AND CONCLUDING REMARKS

It can be seen that the increase of loading from 10 kN (point A) to 70 kN (point C) is shifting the structure toward the critical state, and eventually into the critical state (point B). Each of the points on the straight line corresponds to a specified loading level, and as the load increases (with the increment of 5 kN), the point is moving in the arrow-marked direction. The crack length is kept constant during the calculations (and equal to the initial fatigue pre-crack length), having in mind that the subject of this analysis is crack growth onset. The influence of the joint width on the fracture initiation is analysed in [7], using the local approach to fracture - Gurson-Tvergaard-Needleman (GTN) model.

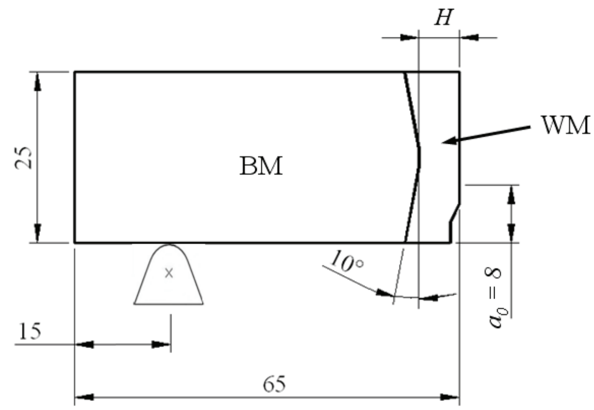

Fig. 1 Dimensions of SENB specimen and welded joint (2H = 6 mm)

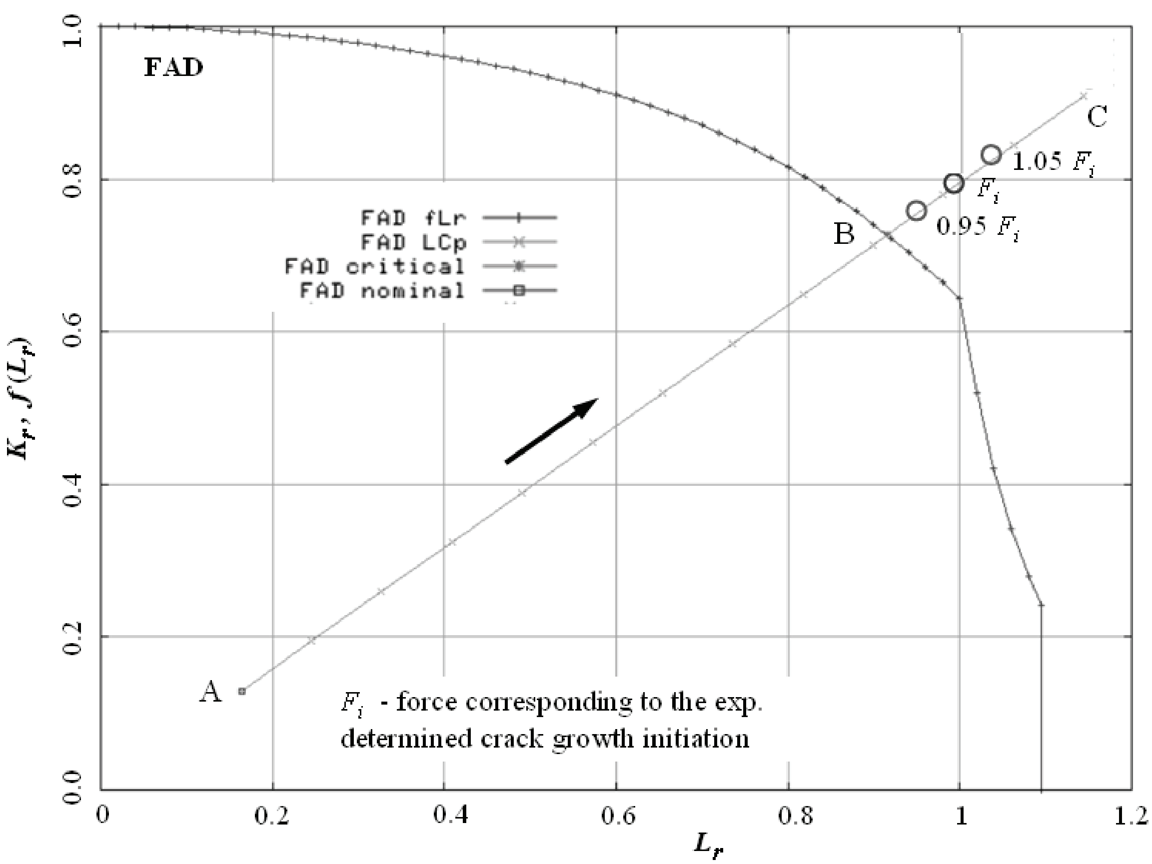

Fig. 2 FAD diagram for welded SENB specimen

The moment of crack growth onset is determined experimentally, and the measured force value that corresponds to it (F_i) is compared with the results obtained using MOSTIS. It turns out that this loading is close to the critical one according to the failure assessment line, because the point that corresponds to F_i at FAD diagram belongs to the critical state of the structure. Therefore, the state of the structure at fracture initiation is correctly predicted, and the assessment using MOSTIS is on the safe side when compared to the experimental investigations, setting a lower loading level as the critical one.

Additionally, the value that corresponds to the experimentally determined crack initiation was varied, in order to check the sensitivity of assessment to the variation of experimental data; the interval $0.95\ F_i < F < 1.05F_i$ was used. It can be seen (Fig. 2) that decrease of this value in amount of 5% brings the appropriate point rather close to the failure assessment line. Having in mind that the crack initiation is difficult to determine exactly, it would be preferable to use a certain safety factor to ensure that the failure assessment will be on the safe-side and will not overestimate the load-carrying capacity of the structure. It can be expected that the highest level of SINTAP procedure would give less conservative results. However, only basic material data are used in the presented example, because they are usually known for most materials in exploitation.

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