Fatigue life tests of steel laser-welded sandwich structures

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ABSTRACT

This paper presents results of the fatigue life tests of elements of steel laser-welded sandwich structure, performed at the Department of Machine Design, University of Technology and Agriculture, Bydgoszcz, in cooperation with the Department of Ship and Offshore Structures Technology, Gdańsk University of Technology, within the frame of ASPIS EUREKA E!3074 project titled : „Application of steel sandwich panels into ship structural design". The obtained information on fatigue features of various specimens, the so called elementary structures of sandwich panels, can make it possible to formulate design and manufacturing recommendations for application of such structures in shipbuilding. An important result of the performed tests is the extended range of fatigue strength data for laser-welded joints.

Keywords: fatigue; laser welding; fatigue life diagrams; steel panel structures

INTRODUCTION

Application of welded joints to building large objects intended for working under changeable loads requires taking into account hazards associated with initiation and propagation of fatigue cracks. Regardless of used fatigue life analysis methods [1] the condition of effectiveness of conducted calculations is to have knowledge on fatigue features of applied welded joints. It is specially important in the case of implementation of novel welding techniques such as laser welding, for which sufficient fatigue data are still lacking.

According to literature sources, there is a lack of commonly applicable guidelines for fatigue life analysis of laser-welded joints, which is the case of traditionally manufactured welded joints [2]. Moreover, the existing results of high-cycle (elastic strain) fatigue tests of smooth specimens containing laser-welded joint [3] indicate that their fatigue strength is close to that of native material.

The problems clearly concern also laser-welded sandwich panel structures constituting the subject of the tests realized within the frame of the ASPIS EUREKA E!3074 project titled : „Application of steel sandwich panels into ship structural design".

Assessment of fatigue features of such structures constituted one of the aims of the tests carried out at the Department of Machine Design (PKM) , University of Technology and Agriculture, Bydgoszcz, in cooperation with the Department of Ship and Offshore Structures Technology, Gdańsk University of Technology, which took part in realization of the ASPIS project.

The tests were carried out at the PKM Laboratory accredited by the PCA (Polish Centre of Accreditation).

PROGRAM AND OBJECTS OF THE TESTS

The program of the tests of elements of steel panel structure has been presented in the form of the block diagram shown in Fig.1. It contains three groups of tests :

- tests under monotonous loading
- preliminary fatigue tests
- main fatigue tests.

The basic aim of the monotonous tests was to determine main static properties of the material specimens as well as elementary structures of various forms. On this basis preliminary ranges of loads used in the fatigue tests were determined among other. Within the frame of the preliminary tests geometrical features of the specimens were verified and finally selected, as well as – in view of complexity of stress and strain distributions in joint – load conditions for the main tests were determined.

Tests of the strain distributions distinguished by broken line in Fig.1, covering the analysis of local

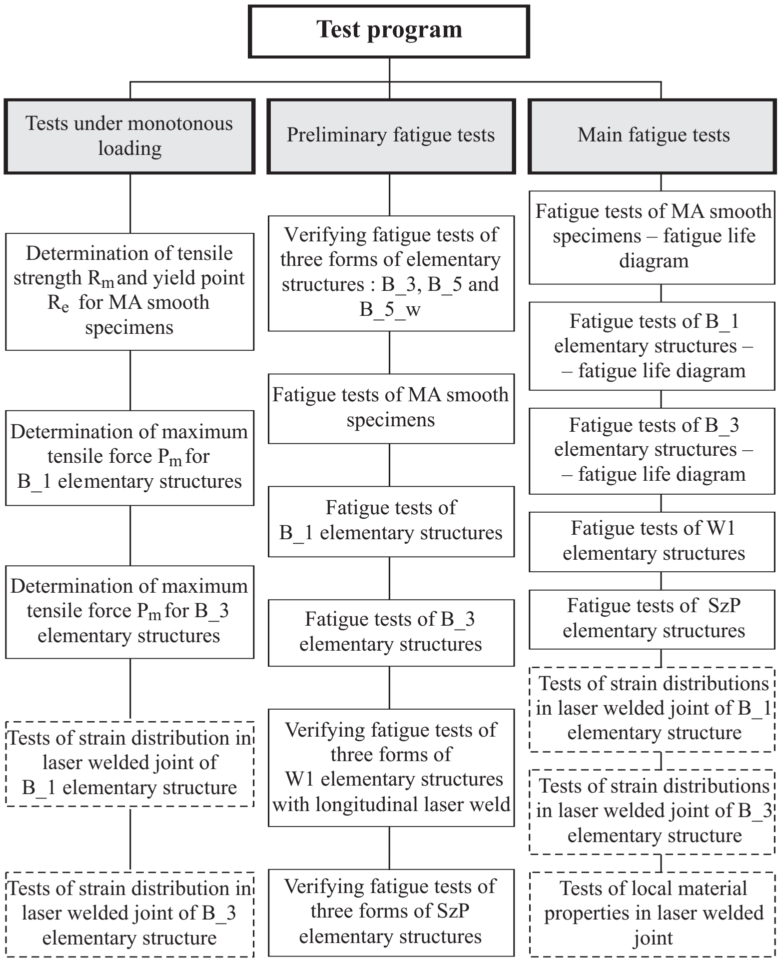
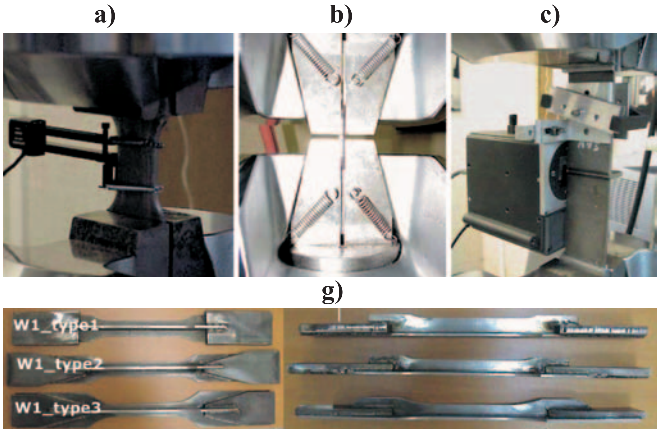


Fig.1. *Schematic diagram of test program .*

strain distributions in laser-welded joints of various elementary structures, constituted a separate scope of the investigations. Some part of the results of the tests were discussed in [4].

The elementary structures used in the tests represented various cases of weld location respective to load direction. Dimensions and geometrical forms of the specimens taken from a steel sandwich panel are shown in Fig.2 and 3.



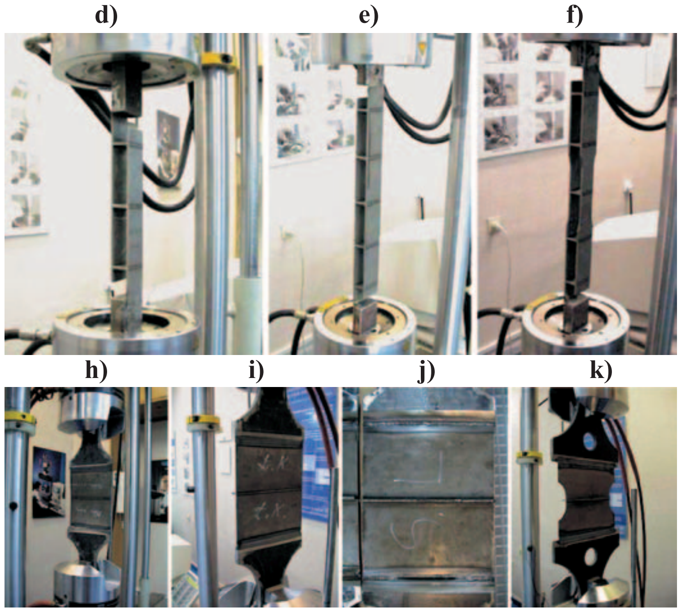
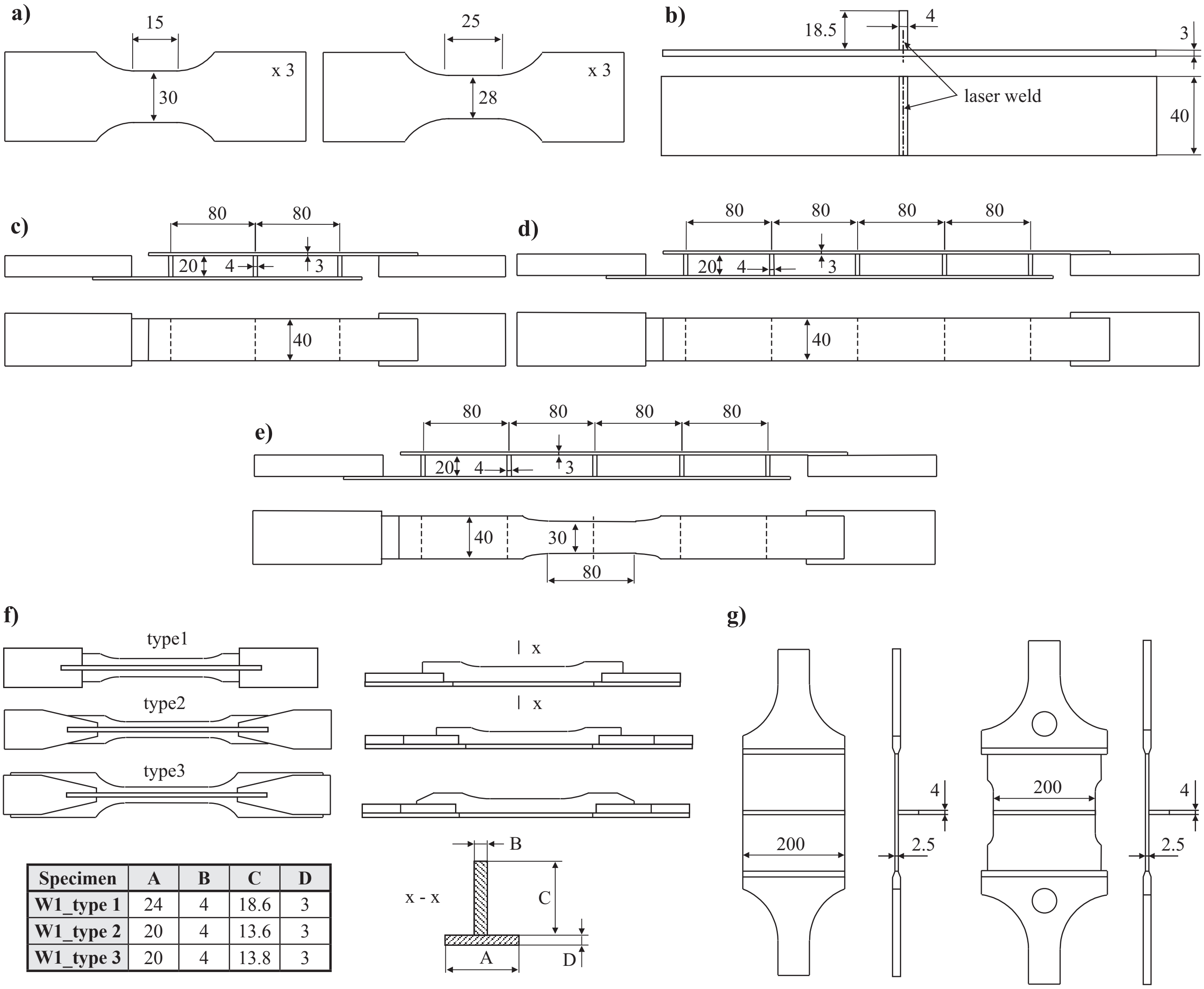


*Fig.2. The specimens and elementary structures used in tests of fatigue properties of sandwich structures: **a)** MA material specimen before modification, **b)** MA material specimen after modification, **c)** B_1 elementary structure, **d)** B_3 elementary structure, **e)** B_5 elementary structure, **f)** B_5_w elementary structure, **g)** W1 elementary structure, **h)** SzP_A elementary structure („mikr.plaz"), **i)** SzP_B elementary structure („l.k."), **j)** SzP_C elementary structure („s.l."), **k)** SzP_D elementary structure.*



Specimen	A	B	C	D
W1_type 1	24	4	18.6	3
W1_type 2	20	4	13.6	3
W1_type 3	20	4	13.8	3

*Fig. 3. Nominal main dimensions of elementary structures of sandwich panel: **a)** MA material specimen before and after modification, respectively, **b)** B_1 elementary structure, **c)** B_3 elementary structure,, **d)** B_5 elementary structure,, **e)** B_5_w elementary structure, **f)** W1 elementary structures : type 1, type 2 and type 3, **g)** SzP elementary structure.*

The tests of smooth specimens and elementary structures were performed according to the PCA procedures approved in the AB372 certificate, in compliance with the PN-EN 10002--1+AC 1:1998 standard – in the case of monotonous loading, and the PN-74/H-04327 standard – in the case of fatigue loading. The fatigue tests were performed in the conditions of controlled variability of force.

RESULTS OF THE TESTS

The detail description of results of the tests carried out in accordance with the particular points of the assumed program, is contained in the reports from realization of the work in the years 2003-2006 [5-8]. In this paper – because of its limited volume – are presented only the results of the main tests, given in the form of fatigue life diagrams for particular types of joints. For MA material specimens, their mechanical properties determined during monotonous tensile tests, are presented additionally.

MA specimens

The aim of the tests of the MA specimens was to determine static and cyclic properties of the material used for sandwich structure plating.

In Fig.4 is shown the monotonous tension diagram obtained for MA specimens, in which are marked the stress values corresponding with their plastic flow, (σ_e), as well as the maximum stress values occurred in the course of loading, (σ_m).

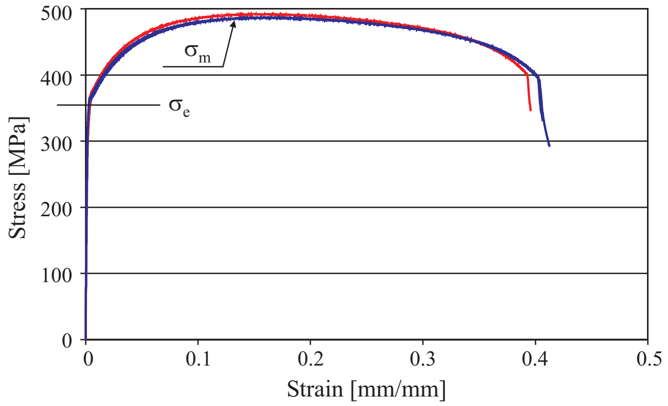


Fig.4. *Diagrams of monotonous tension tests of MA specimens .*

The tests of cyclic properties of the material were carried out at the controlled amplitude of the nominal stress S_a , the constant stress ratio R = -1 (the mean nominal stress S_m = 0), and the load frequency f = 5 Hz. The this way obtained fatigue life diagram expressed in stresses is shown in Fig.5.

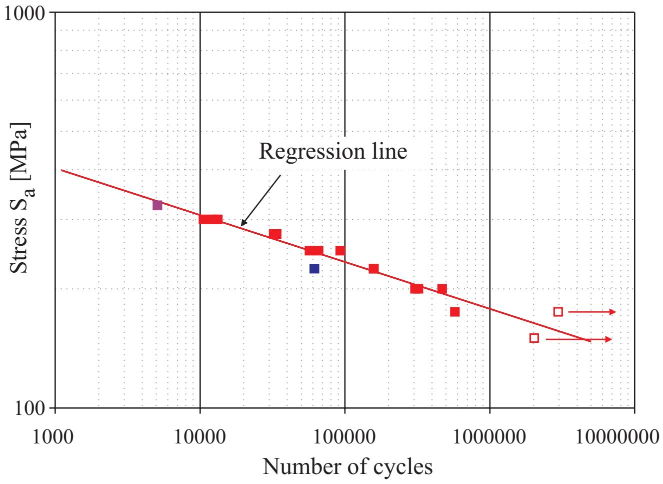


Fig. 5. *Fatigue life diagram of MA specimens .*

B-1 elementary structures

In Fig.6 is presented the fatigue life diagram obtained from the tests of B_1 specimens. The tests were performed at the controlled force and the constant stress ratio R = 0. The data are presented in the bi-logarithmic coordinate frame. The results of fatigue life tests (of all specimens) were approximated by means of the straight line " 1". As the data on fatigue life of the specimens at the loading levels P = 24, 27 and 30 kN were incomplete the regression line „2" was added without taking into account the results of the discontinued tests (distinguished by the arrows). Moreover, the regression line "3" was determined for the set of the data not containing those of the discontinued tests and results of the tests at the loading level P = 54kN, which already entered the low-cycle range of fatigue life.

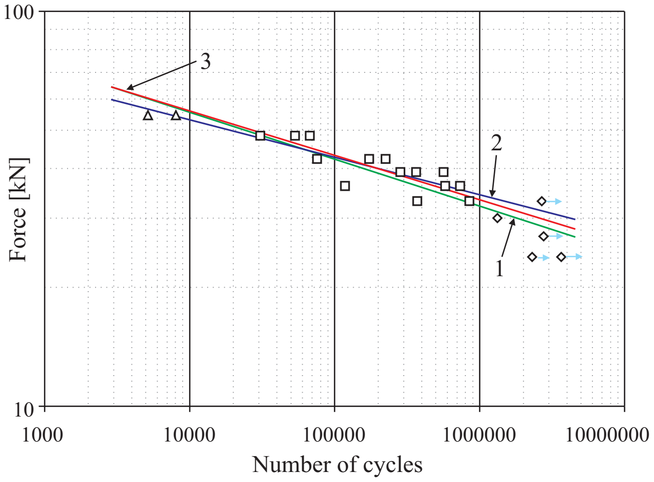


Fig. 6. *Fatigue life diagrams of B_1 elementary structures .*

B_3 elementary structures

Like in the case of the B_1 specimens, tests of B_3 specimens were carried out at the controlled force value and the constant stress ratio R = 0. As a result of the tests was elaborated the fatigue life diagram shown in Fig.7 in the bi-logarithmic coordinate frame "force – cycle number". Results of fatigue life tests (of all specimens) were approximated by the straight line „1". Moreover the regression line "2" for the set of data not containing those of discontinued tests, was determined.

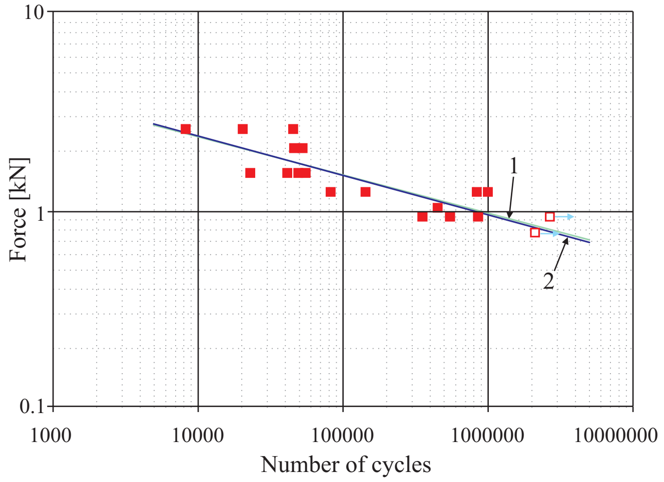


Fig. 7. *Fatigue life diagrams of B_3 elementary structures .*

Analysis of the recorded runs of displacement changes made it possible to observe that the fatigue life of the specimens depended to a greater extent on the displacement range (amplitude) than on the set value of the force range (amplitude). For this reason as well as for comparison purposes was elaborated the fatigue life diagram in the coordinate frame "displacement –

– cycle number", shown in Fig.8; this way much smaller scatter of test results was obtained. Therefore in testing such specimens the fatigue life assessment based on setting displacement amplitude is more appropriate.

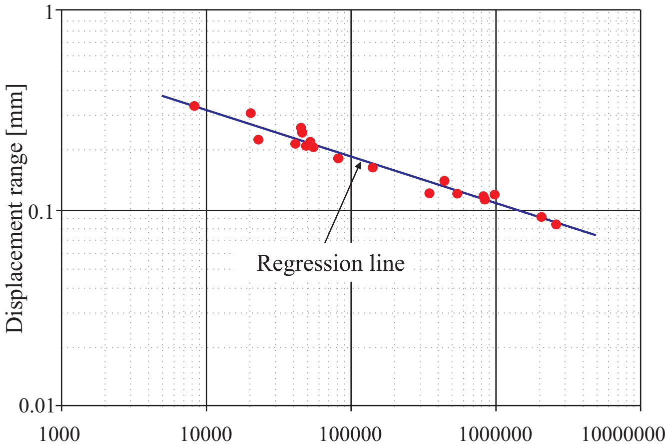


Fig. 8. *Fatigue life diagram of B_3 elementary structure, shown in the coordinate frame "displacement range – cycle number".*

W1 elementary structures

In the main tests of W1 specimens their version marked „type 3" was used. The tests were carried out at the controlled force value, the constant stress ratio R = 0 and the load frequency f = 5 Hz. Results of the fatigue life tests were approximated by the straight line „1" (Fig.9). Moreover the regression line "2" was determined for the set of data not containing those from two tests at the load level S = 425 MPa.

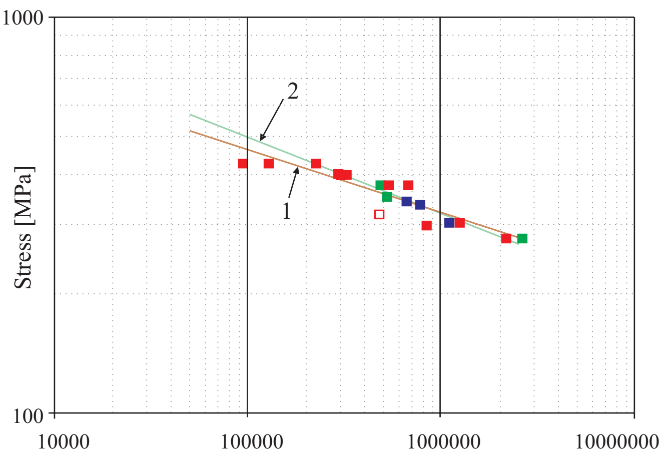


Fig. 9. *Fatigue life diagram of W1_type 3 elementary structure, shown in the bi-logarithmic coordinate frame.*

SzP elementary structures

The tests of the SzP elementary structures were carried out at the controlled force value and the constant stress ratio R = 0. In the tests the specimen version marked „SzP_D" was used. As forms of cracks in specimens were different, to determine the fatigue life diagram shown in Fig.10 only results of the tests revealing cracks in laser weld, were selected. The results of the fatigue life tests were approximated by means of straight line.

CHARACTERISTICS OF THE TEST RESULTS

The presented fatigue life diagrams determined by using the linear regression method were generally characterized by large values of the correlation coefficient R^2, that indicates the scatter of fatigue properties of particular specimens to be rather small.

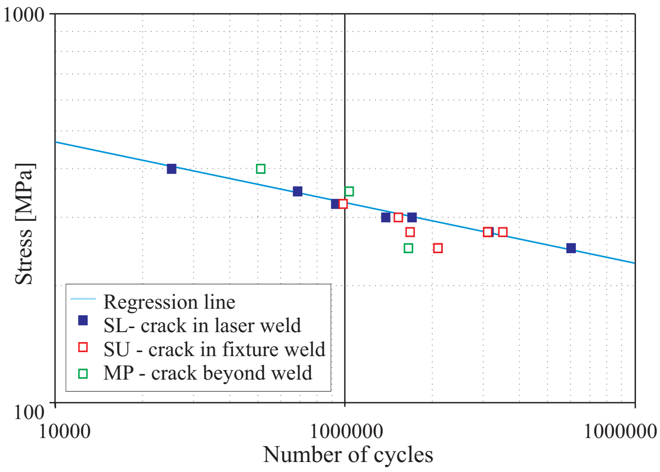


Fig. 10. *Results of fatigue life tests of SzP_D elementary structure.*

It is very favourable from the point of view of the fatigue life calculation methods based on the so called design diagrams. The small fatigue life scatter of the tested specimens confirms also that laser-welded joints behave favourably, which results mainly from their high uniformity in the joint zone (repeatability of their geometrical and material features).

SUMMARY

- The results of the performed tests constitute a rich source of data useful in analyzing fatigue phenomena occurring in steel sandwich panel structures under cyclic loading.
- The obtained information on fatigue properties of various elementary panel structures can make it possible to formulate design and manufacturing recommendations for the application of such structures to shipbuilding.
- Simultaneously, the fatigue life diagrams determined during the tests can be directly applied to fatigue life calculations of ship panel structures by using the methods based on the guidelines of Polish Register of Shipping.
- An important result of the performed tests is the extended range of fatigue strength data for laser-welded joints, indispensable in building the knowledge base on results of fatigue tests performed for structures built with the use of novel welding techniques.

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