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MODELING OF A THREE-POINT BEND TEST OF A BEAM MADE OF AW 5083 ALLOY

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Abstract: The paper describes the modeling of a three-point bend test carried out on a beam made of the AW 5083 aluminium alloy performed using the finite element method. The three-point bend test was carried out experimentally in accordance with the current standard PN-EN ISO 7438:2016-0. During the test, the values of the beam material constants, such as Poisson number and Kirchoff modulus which were necessary for the modeling were determined. The results obtained in the test allowed for modelling using software based on the finite element method, such as MSC Patran and Abaqus software. The test modelling in the software was performed taking into account the beam geometry, the material properties, the boundary conditions, and the load. In order to verify the model, a comparative analysis was performed of the values of the bend of the beam's central axis obtained from the experiment and the values obtained after the FEM modeling and those obtained by the analytical method.

Keywords: numerical modeling, bent beam, Abaqus, MSC Patran, analysis, FEM.

1. INTRODUCTION

Aluminium alloys are used successfully in offshore and onshore construction, aviation, transport, and even space engineering [Kaufman and Rooy 2004]. These materials have relatively good strength properties, which can be additionally increased by heat treatment, e.g. by precipitation strengthening (supersaturation and ageing) [Hajdukiewicz 2018]. Another way to improve the properties of aluminium alloys is to use alloying additives [Jurczak 2006]. The disadvantage of constructals – alloys of the 7XXX group is their susceptibility to stress corrosion cracking in the seawater environment [Bugłacki and Kłyszewski 2001], which makes their use in shipbuilding difficult. Aluminium alloys of the 5XXX group (hydronalia) are not as strong as the above-mentioned constructals and are characterised by medium strength properties and good resistance to corrosion, especially stress corrosion. The material chosen for the tests was a material from this group, i.e. the AW-5083 alloy (ISO: AlMg4,5MnO,7), which is successfully used in the shipbuilding, automotive, construction, chemical, and food industries. This alloy is also used in production of weldable parts, machine parts, masts, chemical devices, in weldable structural elements, tanks, and pipeline components.

The AW5083 aluminium alloy is a part of the group of alloys of aluminium and magnesium. It is characterised by medium strength with very high corrosion resistance. It is suitable for welding and anodising. It is characterised by very good corrosion resistance in the marine environment and good suitability for application of conversion coatings, and at the same time it is well weldable [Kyzioł and Komarov 2002]. It is also characterised by high fatigue strength at temperatures below 70°C. Due to these characteristics, contemporary designers in various industries are willing to use these materials [Davis 2004].

In Poland, the AW 5083 alloy was used in shipbuilding as early as in the 1960s. It is used for construction of hulls of small high-speed craft, superstructures, and various types of ship equipment and accessories. Aluminium alloys are used to build hulls of vessels is due to the fact that these alloys make it possible to significantly reduce the weight of ship structures compared to the weight of steel structures. By using aluminium alloys, it is possible to reduce the weight of the hull by as much as 50%, which reduces the ship's displacement or, if the displacement is to be maintained, increases the load capacity or speed, and improves stability. This is why aluminium alloys are used in construction of ships or displacement vessels, as well as in construction of non-displacement vessels, such as hovercraft or hydrofoil boats [Bujniewicz, Cudny and Wincza 1971].

Due to the demanding nature of the operating conditions and environments in which seagoing vessels operate, their welded components and structures are subjected to high loads, which causes microstructural degradation and may ultimately lead to failure. As the use of aluminium is expanding in the shipbuilding sector, a lot of research is being carried out that focuses mainly on the fatigue properties of this material. The earliest documented structural tests of aluminium alloy elements that were subject to bending were described at the beginning of the previous century [Dumont and Hill 1940]. Since then, many experimental and numerical tests have been carried out in order to clarify the regulations concerning designs of structures made of aluminium alloys based on the parameters obtained from strength tests.

The purpose of the paper is to model a three-point bend test of a beam made of the AW 5083 aluminium alloy. To model the beam, algorithms implemented in the MSC Patran and Nastran software and the Abaqus software were used. Numerical calculations were carried out for two different sets of material constants E and ν (Young modulus and Poisson number). The first set is the values of material constants obtained from the literature on the AW 5083 alloy. The second set of data was obtained from tensometric measurements of the beam that was subject to bending.

In the literature on the subject, the main subject of similar studies is problems related to numerical modeling of samples and numerical simulation of the conducted test. In the case of the modeling of three-point bending, an analysis of fatigue cracking initiated during such tests is also described [Pradeau, Thuillier and Yoon 2016; Dashwood et al. 2018]. Numerical modeling of strength tests is also performed to study the strength of coatings applied on aluminium alloys.

2. TEST MATERIAL AND METHODOLOGY

The tested beam was made of a milled sheet made of the EN AW-5083 aluminium alloy. The chemical composition of the sheet was determined by means of a spark-excited optical emission spectrometer of the Solaris CCD Plus type made by the Italian company G.N.R. Optica – Analytical Instruments Group.

Table 1 shows the chemical composition of the tested sheet. The sheet was manufactured in accordance with the PN-EN 10204 standard, attestation 2.1 (declaration of conformity); the declaration contains information about the conformity of the manufacture of goods in accordance with the relevant standard without providing the test results.

A schematic diagram of the support and the load on the beam with dimensions are shown in Figure 1.

Using the values of elastic constants, the deflection values (in the elastic range) were calculated depending on the value of the force. The laboratory bend tests performed on the beam in the elastic range consisted in a measurement of the deflection value caused by an external force F. The deflection values were measured with a dial sensor.

The bend test was carried out on a stand by loading and subjecting the beam to three-point bending. The bend test was carried out in accordance with the current standard PN-EN ISO 7438:2016-0. The deflection of the beam was measured with a dial sensor with measurement accuracy of 0.01 mm.

The results of the numerical calculations carried out for the beam subjected to three-point bending for both sets of material constants were finally compared with the results obtained by analysis and with the results obtained in laboratory conditions. The results are briefly analysed in the conclusions.

Table 1. Chemical composition of rolled, milled sheet made of the EN AW-5083 alloy, determined by means of the Solaris CCD Plus optical emission spectrometer

Aluminium alloy	Chemical composition [%]										Declaration of conformity
5083	Mg	Mn	Fe	Si	Cu	Cr	Zn	Ti	Ga	Al	2.1 PN-EN 10204:2006P
	4.27	0.31	0.35	0.28	0.04	0.06	0.01	0.02	0.03	the rest	

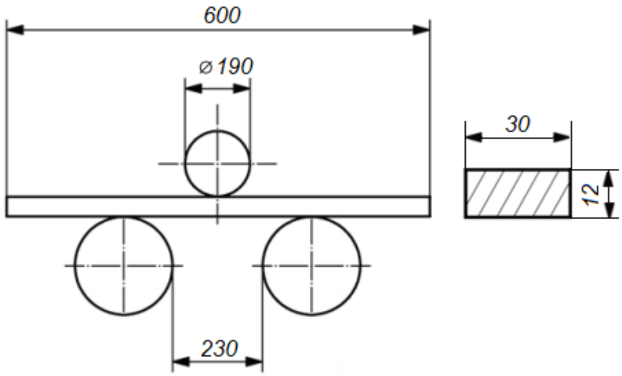

Fig. 1. A schematic diagram of the beam support and load

To determine the Poisson number ν of the material of the tested beam, two independent tensometric systems were placed on the top and bottom surface of the beam to measure the longitudinal and transverse deformations (Fig. 2).

The two independent systems, which consisted of 4 grid type electric resistance wire strain gauges on a paper substrate, were connected in a full bridge arrangement each.

The bending deformation values of the beam were recorded using a ZEPWN recorder of the CL 460 type.

The Poisson number was calculated as the ratio of transverse ε_{m2} to longitudinal ε_{m1} deformation, i.e. $-\nu = \varepsilon_{m2} / \varepsilon_{m1}$.

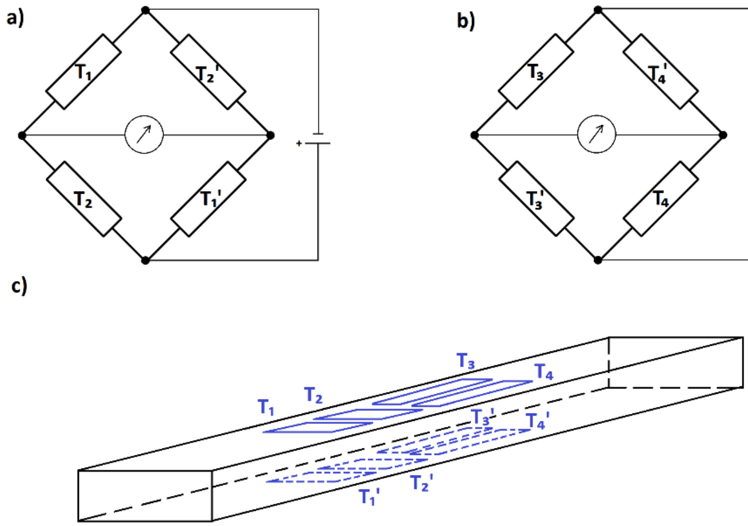

Fig. 2. A diagram of the measuring system to determine the Poisson number using a strain gauge system: a) a system of strain gauges measuring the strain across the sample, b) a system of strain gauges measuring the strain along the sample, c) a diagram of the location of the strain gauges on the beam

The Poisson coefficient characterises deformation of elastic materials. This value is defined as the negative ratio of the relative change in the transverse dimension of a material to the relative change in its longitudinal dimension if these changes result from a homogeneous stress acting in the longitudinal direction.

3. RESULTS OF EXPERIMENTAL RESEARCH

Tables 2 and 3 show the test results obtained during beam bending. Moreover, Table 3 provides material constants published in literature.

Based on the results of the bend test, the deflection value and the Poisson number were determined. The value of the Poisson number obtained from the tensometric measurements was assumed as the first set of material constants and was marked as ν_1. In the process of bending of beams in the elastic range, the beam deflection was recorded; the bending results made it possible to determine the Young modulus and were marked as E_1.

As the second set of material constants to determine the deflection (for comparison) for the tested alloy, the data from the website of the Kronos EDM metallurgical products distribution center were used. These data are marked as ν_2 and E_2.

Table 2. Results of the three-point bending of the beam

Beam loading force [N]	**Beam deflection [mm]**	**ε_{m1}, [μm/m]**	**ε_{m2}, [μm/m]**	**$v = \varepsilon_{m2}/\varepsilon_{m1}$, [-]**
167.3	1.28	173.5	-54.8	0.3159

Table 3. List of material constants assumed for numerical modeling of the beam bend test

Material constants obtained from the beam bending test			**Material constants from literature/Internet**		
v_1 [-]	E_1 [MPa]	G_1 [MPa]	v_2 [-]	E [MPa]	G_2 [MPa]
0.32	71	26.21	0.33	71	26.8

The values of the material constants shown in Table 3 are very similar, which proves the correctness of the tests. These results enable numerical calculations of the deflection of a beam made of the AW 5083 alloy.

4. RESULTS OF BEAM DEFLECTION CALCULATIONS

On the basis of the material data for the EN AW 5083 alloy contained in Table 3, the beam deflection was calculated using the MSC Patran-Nastran and Abaqus software, and the analytical calculations were performed. The results of the calculations were verified by the beam deflection results obtained in the experimental research.

During the construction of the numerical model, when modeling the bend test in the MSC Patran, Nastran, and Abaqus software, the 'beam' type – a three-dimensional element with 6 degrees of freedom in each node – was selected as the finite element. The plot function in such an element is determined by square interpolation. When creating a finite element grid, the beam elements were selected. In each software, two numerical models of the bent beam, which differed by the values of material constants, were prepared.

Figures 3 and 4 show a visualisation of beam deflection using the MSC Patran-Nastran and Abaqus software for experimentally obtained material constants. There is a great convergence of the results obtained.

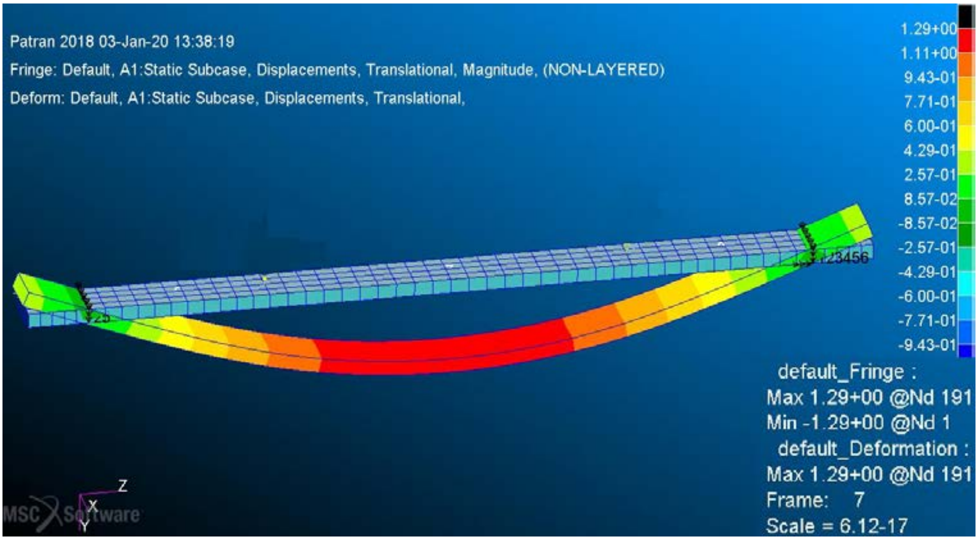

Fig. 3. Deflection *f* of the beam using the MSC Patran – Nastran software for experimentally determined material constants (ν1 = 0.32, G1 = 26.21 GPa), *f* = 1.285 mm)

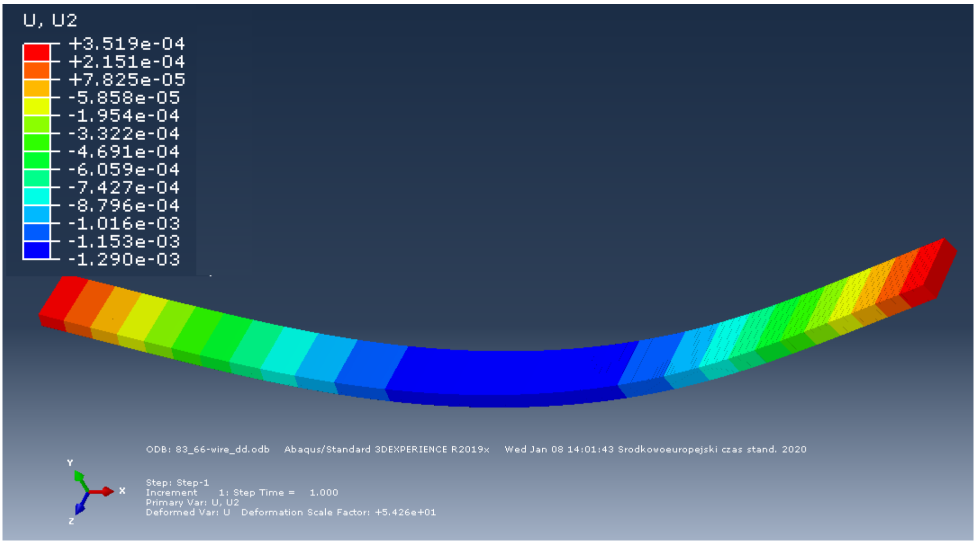

Fig. 4. Deflection *f* of the beam using the Abaqus software for experimentally determined material constants (ν1 = 0.32, G1 = 26.21 GPa), *f* = 1.290 mm)

Figures 5 and 6 show a visualisation of beam deflection after the bend test has been modeled in the MSC Patran – Nastran and Abaqus software using material constants from literature. Again, there is a great convergence of the results obtained using the two methods.

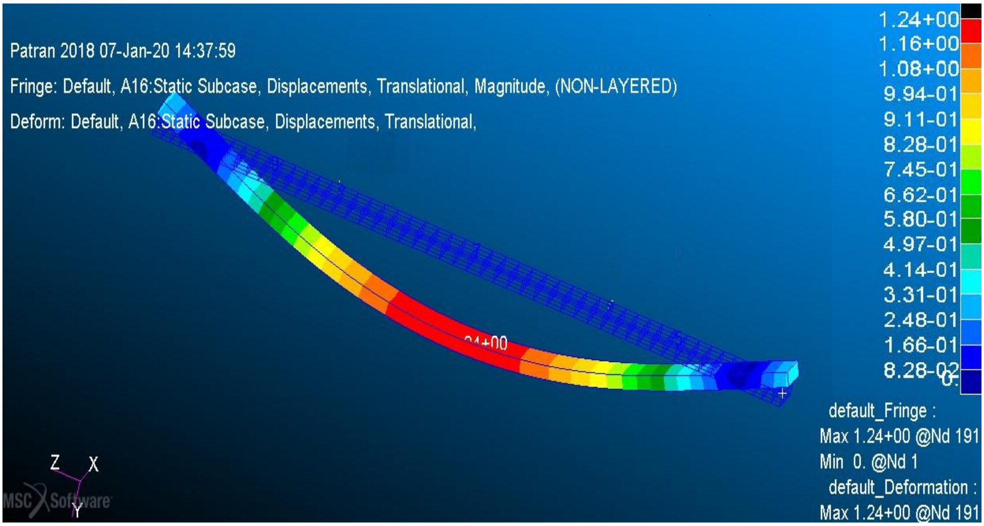

Fig. 5. Deflection *f* of the beam using the MSC Patran and Nastran software for material constants from literature ($\nu_2 = 0.33$, $G_2 = 26.8$ GPa), *f* = 1.241 mm)

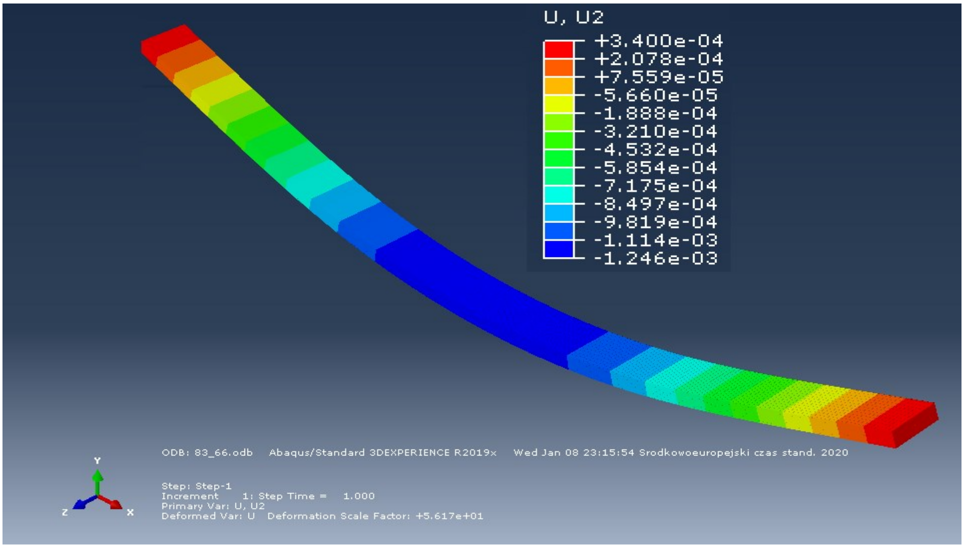

Fig. 6. Deflection *f* of the beam using the Abaqus software for material constants from literature ($\nu_2 = 0.33$, $G_2 = 26.8$ GPa), *f* = 1.246 mm)

Tables 4 and 5 show the results of beam deflection obtained using the numerical, analytical, and experimental methods.

Table 4. Beam deflection values for Poisson number ν_1 and Young modulus E_1.

F[N]	Deflection determined experimentally f, [mm]	Deflection determined using the MSC Patran software f, [mm]	Deflection using the Abaqus software f, [mm]	Deflection determined analytically f, [mm]
167.3	1.28	1.285	1.290	1.285

Table 5. Deflection values for Poisson number ν_2 and Young modulus E_2

F[N]	Deflection determined experimentally f, [mm]	Deflection determined using the MSC Patran software f, [mm]	Deflection using the Abaqus software f, [mm]	Deflection determined analytically f, [mm]
167.3	1.28	1.241	1.246	1.285

The results shown in Tables 4 and 5 prove the correctness of the calculations made. Both the Patran-Nastran method and the Abaqus method showed very high compatibility with the experimental results. Moreover, the material constants determined experimentally and those obtained from the literature show very high compatibility. This is very important in the case of structural calculations based mostly on literature data.

In the literature, numerical models are frequently verified by experimental tests. In numerical simulations, it is common practice to strive to simplify the numerical model as much as possible due to the complexity of the algorithms used to analyse such a model and the computing power of the users' computers.

Using a numerical model created with the use of computational software, i.e. Abaqus or the Patran and Nastran package, can reduce the time it takes to estimate the safety of engineering structures and to reduce the cost of experimental tests.

5. CONCLUSIONS

The purpose of the paper is numerical modeling of a three-point bend test taking into account the unique characteristics of the material and the boundary conditions resulting from the experimental tests. The results of the numerical analysis of the models were compared with experimental results.

A three-point bend test of a beam made of the AW 5083 aluminium alloy was carried out and numerical calculations were performed on its basis. The numerical modeling used the MSC Patran and Nastran software package and the Abaqus software. The tests showed, on the basis of simple three-point bending, that if a mathematical model is implemented correctly, the results will converge regardless of the type of software. The calculation results are confirmed by the experimental results. It is very important to prepare the data carefully for the calculation, because the final result depends on it. In the Abaqus software, as in other software based on the FEM method, the model can be built in several ways. Discretisation involving the choice of the type and the number of finite elements determines the correctness of the obtained solution in the context of the approximate nature of the FEM.

The MSC Patran and Nastran software and the Abaqus software are characterised by use of a very advanced finite element method. They are among the world's leading software based on the finite element method. Practically every engineering task can be analysed with this software. The problem in applying such software is its complexity. The user has to have theoretical knowledge and experience in using this software in order to achieve useful results of the simulations.

The concept of the finite element method implemented in both software applications used in the paper for numerical simulation assumes that displacement and stress are described by means of a continuous function in a given area (a continuous part of a physical model) and are approximated by a discrete model. Since the actual shape of the analysed structures rarely has a uniform geometry, the FEM requires various shape-simplification procedures in order to create an optimal grid to represent the object.

The finite element method, like any numerical approximation method, introduces a number of possible solution errors, i.e. a modeling error (when the applied mathematical model does not accurately reflect the reality), a coefficient value error (e.g. erroneous material data), a numerical error (discretisation error), and a rounding error. Consequently, numerical calculations can be a good alternative to laboratory tests but only if the numerical model is verified.

Nowadays, simulation is the way to design better and cheaper products and solutions. Simulation allows engineers to analyse their theories and assumptions using mathematical equations and the enormous computational power of constantly-developing software and hardware. This can be done without the cost of production of a physical prototype.

The results of the study justify the claim that experimental tests play a key role in the design of structures. They support and verify numerical studies.

Currently, a growing field is numerical simulations of tests of aluminium alloys used in, among others, sandwich structures and aluminium foam structures. Fatigue cracking analyses of structures made of aluminium alloys are also widely discussed.

ADDITIONAL NOTES

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