FEM strength analysis of sandwich panels for ship structure applications

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ABSTRACT

This paper presents results of the numerical simulation modelling strength tests of laser-welded, foam-filled steel panels, performed by means of the Finite Element Method (FEM) within the frame of the ASPIS project. In this case application of the FEM makes it possible to significantly lower costs of determination of mechanical properties and optimization of the structure respective to its strength-weight ratio. The entire project as well as the presented calculations are aimed at implementing structures of the kind to shipbuilding industry. Results of the calculations modelling axial compression of panels comply with experiments qualitatively. The entire process of the structure's compression till its collapse resulting from extensive plastic deformation within its middle zone, was step-by-step examined. Also, critical forces causing instability of the structure were determined. A partial quantitative discrepancy of the calculated reaction forces and those experimentally measured, requires further investigations.

Keywords : sandwich structures, plastic buckling, Finite Element Method (FEM)

INTRODUCTION

Sandwich panel structures (SPS) are more and more widely applied in various industrial branches, a.o. in building [1,2] and aircraft industry. Their high density/ strength ratio makes them an attractive alternative for traditional ship structures. A part of the solutions has been already standardized [3], however the SPS are continuously optimised in the world.

At Gdańsk University of Technology in the frame of ASPIS project were performed laboratory tests of large-scale prototypes of steel panels to be applied – after their optimisation – to ship hulls. Implementation of such structures requires first of all to determine their resistance to tension and bending loads, as well as to design optimum joining systems and optimise their strength/mass ratio and cost. Because of large costs of experimental tests it was decided to conduct a part of the investigations by means of the finite element method (FEM) [4].

In this paper are presented results of numerical simulations of behaviour of such panels under uniaxial compression along axis of stiffeners (webs) where influence of two parameters : laser-weld width and web depth, has been considered. Five variants of weld width (1, 1.5, 2, 3 and 4 mm) and two variants of web depth (20 and 60 mm) were assumed in accordance with the series of types established by the project co-ordinators. *I-core* panels filled with polyurethane foam, were built of 3 mm steel shell plating and 4 mm webs of 80 mm depth. The overall dimensions of a single panel reached 6000x1000 mm.

The calculations in question were performed with the use of two methods. Results from the first of them was assumed to be the first approximation. It consisted in determining the critical buckling force for the panel, the other – in step-by-step investigating the course of the compression process of the structure till its collapse resulting from extensive plastic deformations in its middle zone. The instant of collapse was arbitrary assessed – – it was assumed that the occurrence of visible local buckling of cover plates in the plane of the maximum deflection of the panel stands for the state of sandwich panel collapse.

FEM MODEL

In accordance with the real prototype structure the higher strength steel RAEX 355 MC LASER (of the tensile strength R_m = 450 - 510 MPa, and the yield strength R_e = 355 MPa) was selected for shell plating (cover plates) and St3 structural steel (of R_m = 425 MPa, and R_e = 235 MPa) for webs. As R_m value of the first steel was given within certain range, for the calculations its mean value equal to 480 MPa was assumed. Both the steels were characterized by the same initial value of Young modulus equal to 206000 MPa. The bilinear strain-stress model was assumed in which elastic behaviour is valid within small deformation range only and beyond it the material behaves in compliance with the following hardening modulus formula :

$$E_{tt} = (R_m - R_e) / [(A5 / 100) + (R_m - R_e) / EX)]$$

where :
R_m – tensile strength
R_e – yield strength
A5 – total elongation of the A5 specimen after breaking
EX – Young modulus

Copper material of the distance plate between the steel pad to which the compressive load is applied, and the tested panel itself, is characterized by the single Young modulus equal to 100000 MPa. For the polyurethane foam filling the Young modulus of 12 MPa was assumed.

The FEM model consisted of about 13.000 SOLID186 finite elements as well as CONTA174 and TARGE170 contact ones placed in the gap in the laser-weld area.

The panel underwent full parametrisation process, and its most important parameters were in accordance with the authors' notation, as follows :

DC	- internal distance between cover plates
DIVDC	- number of divisions over the web depth
L1	- web thickness
T1	- plating thickness
SC	- gap between plating and face of web end
SP	- weld width
RX	- web spacing
PPZ	- area to be analysed along web axis
PODZZ	- division into elements in the indicated direction
APODZZ	- concentration of the division into elements in the indicated direction
ILP = 6	- number of closed boxes
PPX	- area to be analysed in the direction perpendicular to webs

On the basis of several test computations it was determined that the minimum number of divisions along webs of the panel 3000 mm long, was equal to 10, hence for the main analyses 14 divisions gradually denser towards the plane of maximum deflection of the panel, were assumed.

RESULTS

Table shows the critical force values determined from the linear buckling analysis, at which the panel buckling and collapse takes place.

Values of maximum reaction forces [N] .

Weld width [mm]	Model No. 3 (web of 20 mm depth)	Model No. 12 (web of 20 mm depth)
1.0	89112	382778
1.5	89240	382254
2.0	89315	382778
3.0	89414	383299
4.0	89462	383592

The below presented diagrams show values of the reaction force recorded during gradual shifting the compression machine traverse, with the step of 1 cm. The results were obtained from the non-linear elastic-plastic analysis.

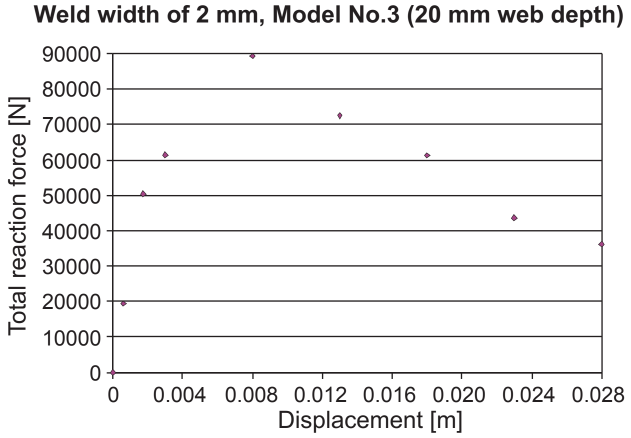

Fig.1. *Reaction force values obtained from elastic-plastic analysis .*

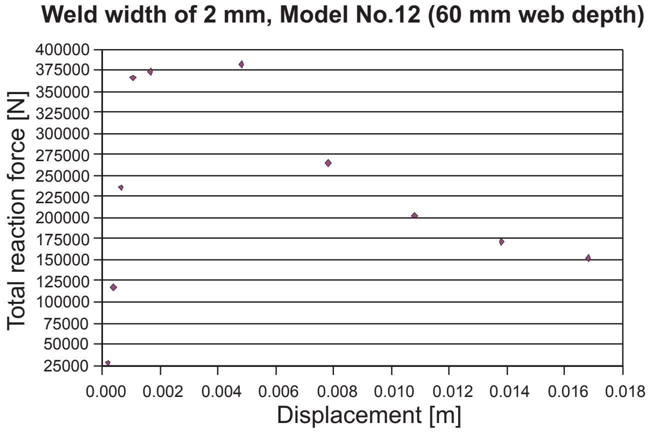

Fig.2. *Reaction force values obtained from elastic-plastic analysis .*

Some contour maps are attached in the end of this paper. Fig.5 and 6 show deformations in the middle plane of the panel model of 1 mm weld width and 20 mm or 60 mm web depth, respectively. Fig.7 and 8 illustrate the reduced stresses in the panel model of 20 or 60 mm web depth, respectively. Fig.9 and 10 present results for another variant of the panel, namely that of 60 mm web depth and 3 mm weld width, where the plastic deformations and reduced stresses compared with those for the panel model of 1 mm weld width, as an example, can be found.

Important seems to be a comparison of the results of the linear-buckling analysis and elastic-plastic one. The first yields the critical force value of about 94 kN and 780 kN, for 20 mm and 60 mm web depth, respectively. The increase of the critical force value by almost one order of magnitude as a result of tripling the web depth, complies with the Euler theory of plates (the critical force increase proportional to the square of plate thickness).

The observed very small influence of weld width on the critical force is hard to be explained. However it can be argued that the joints between cover plates and webs do not transfer any significant loads under compression, and the FEM analysis shows that in the vicinity of the welds are present no significant stresses which could trigger a failure mechanism dependent in a certain way on width of the welds.

The full non-linear analysis with plastic deformations taken into account brings – for 20 mm web depth – the results identical with those from the linear analysis. In the case of 60 mm web depth an excessively sparse step of calculations was assumed that resulted in omitting a peak value of reaction force. However the run of the functions on both sides of the critical range of deformations indicates that also for 60 mm depth of webs the critical force could achieve a value close to that calculated from the linear-bucking analysis. The assumed sparse step of calculations was forced by hardware and time limitations.

The form of local failures of the panel is worth observing (Fig.3 and 4). In the plane of the maximum deflection of the panel after global buckling, reaching more than 20 cm, also

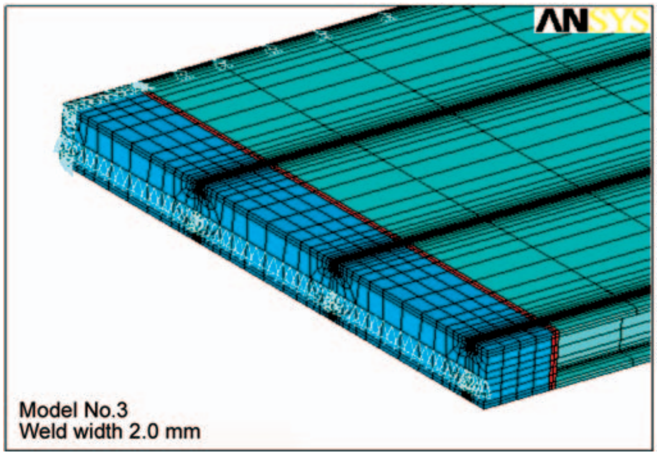

Fig. 3. *A view of compression traverse .*

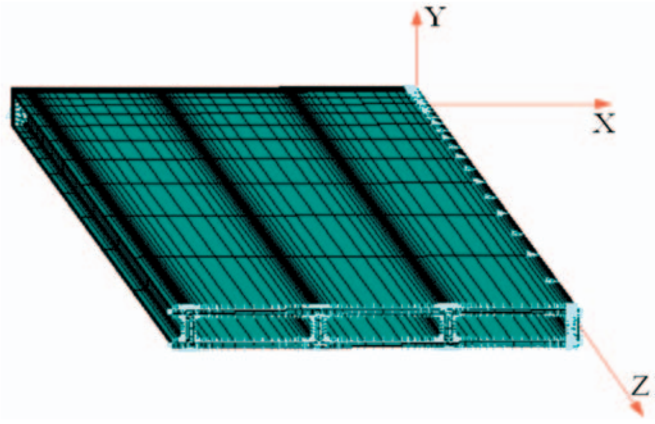

Fig. 4. *A quarter of FEM model with supports .*

local buckles of cover plate strips between neighbouring webs, occur. The alternating sense of the maximum local deflections of the plates which underwent buckling, is characteristic.

At the end, worth mentioning is the correct qualitative conformity and quantitative discrepancy of the experimental and numerical simulation results. Reasons for the discrepancy could be associated with an insufficient density of numerical model mesh along the webs, which constitutes a compromise between calculation accuracy and hardware capabilities and cost of the research. Another possible cause can be some discrepancy between the way of modelling of the copper distance plate and the traverse compressing the panel.

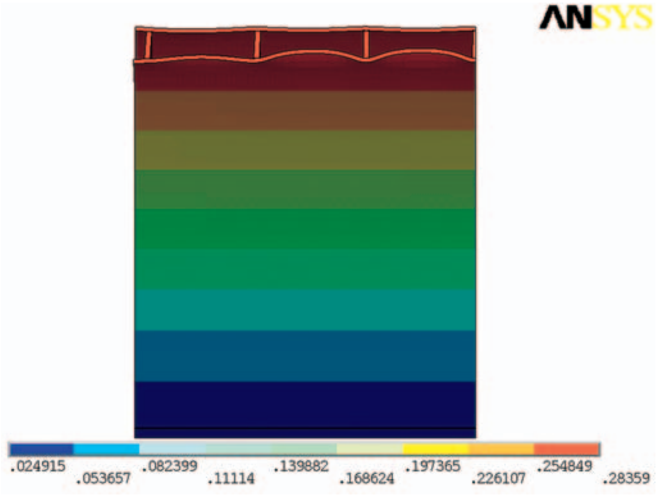

Fig. 5. *Displacements and failure mode of the panel of 20 mm web depth and 1 mm weld .*

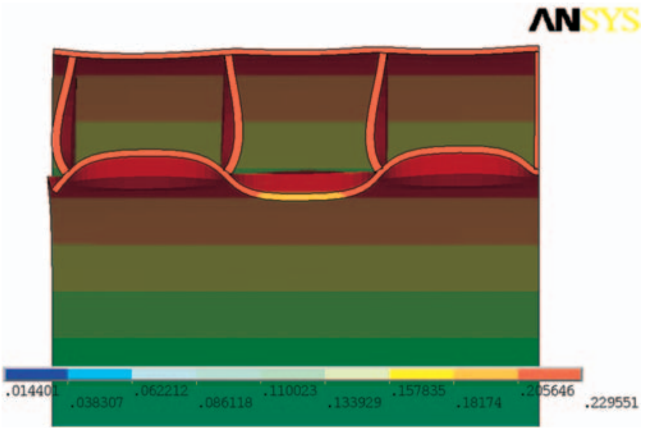

Fig. 6. *Displacements and failure mode of the panel of 60 mm web depth and 1 mm weld .*

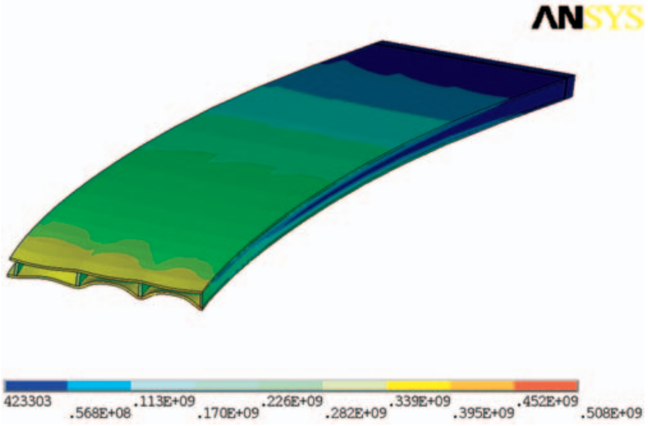

Fig. 7. *Reduced stresses in the panel of 20 mm web depth and 1 mm weld .*

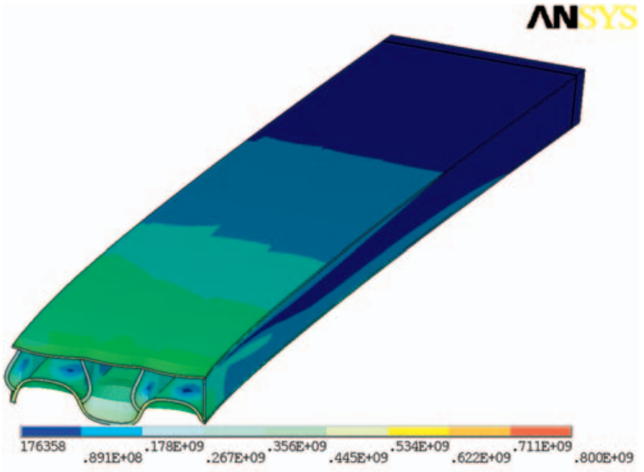

Fig. 8. *Reduced stresses in the panel of 60 mm web depth and 1 mm weld .*

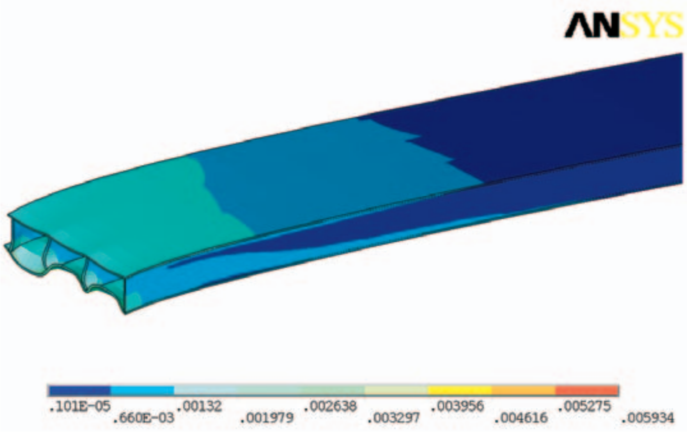

Fig. 9. *An example map of plastic deformations in the panel of 60 mm web depth and 3 mm weld .*

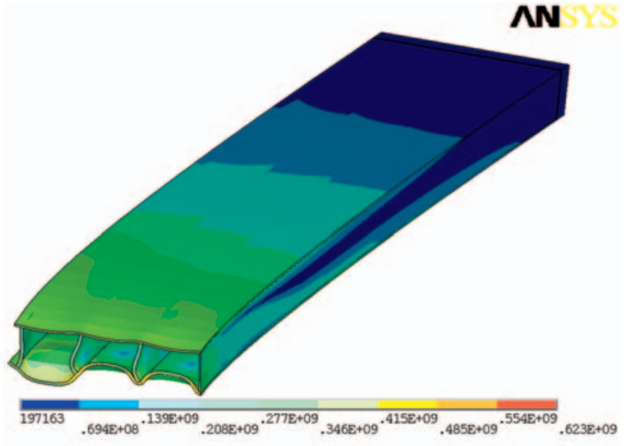

Fig. 10. *Reduced stresses in the panel of 60 mm web depth and 3 mm weld .*

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