Numeric simulations of surface pressure and microslip phenomena occurring in riveted joints of semi-monococque structures in effect of the action of tension field

JAROSŁAW MAŃKOWSKI

Jarosław Mańkowski (jaroslaw.mankowski@simr.pw.edu.pl), Warsaw University of Technology, Warsaw, Poland

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Abstract

Tension fields are shown to have an influence on surface pressure and on material deformation in the riveted joints in thin walled structures and particularly in semi-stressed skin structures. Stresses and materials displacements were analyzed in the riveted joints performing under such conditions. Special attention has been attached to estimation of the microslips occurring between rivets and holes. A thin plate panel has been used for the test sample, which under effort condition revealed tension fields.

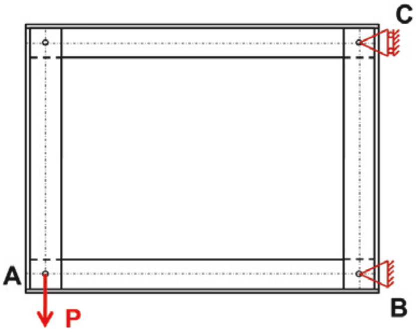
KEYWORDS: **riveted joints, micro-slips, thin walled structure, semi-monococque**

Introduction

It is commonly believed, that rivets installed in riveted joints on thin walled structures should mainly take the loads acting square to their longitudinal center line. For this reason, respective calculations are usually limited to shear stresses and to surface pressure efforts in material. This practice emerges from the fact, that deformations in the matching parts which transmit the loads acting in parallel to longitudinal center lines of the rivets are usually very small. The situation is totally different in the semi-monococque structures, where resilient loss of stability of the covering is acceptable for service loads. This is particularly true when framework of the construction is asymmetrical with the covering installed on one side only. In such case, once the critical force has been exceeded, the mode of operation of the rivets would entirely change. In addition to resistance to shearing and to surface pressure forces, they start to perform in tension and bending. This should lead to conclusion, that in the semi-monococque air structures with the critical force exceeded and with buckling of coverage, the joint performance character of the joint would undergo substantial change. This may involve coming into existence local accumulation of contact stresses between rivets and holes and also significant microslips may tend to appear in both circumferential and in parallel direction patterns. Attention is drawn in [4–6] to considerable circumferential microslips occurring in conventionally performing rivet joints. In case of matching of these with local accumulation of contact stresses, phenomenon of fretting might reveal, which would substantially reduce the joint operating life [7, 8]. Consequently, tests have been carried out to investigate performance conditions of matching faces of the rivet joints in a semi-monococque construction already known to reveal tension field in response to burden.

Subject of investigation

Submitted to the tests was a rectangular thin walled panel with the frame members located on one side of coverage. The panel components were assumed to be cast aluminum grade D16TN, but the rivets were from alloy grade PA25. For construction details, methods of mounting and load pattern see Fig. 1. Corresponding to this panel is critical force of 3909 N, which means that cover stability would be lost at a burden of 46.3% of maximum force (9000 N).



Specification:
Vertical and horizontal members of framework:
angle bar 25×25×3 mm,
metal sheet gauge: 1 mm,
rivets dia: 2.5 mm,
pitch: 12 mm,
load: P = 9000 N

Fig. 1. *Subject of investigation: dimensions, mounting, loads*

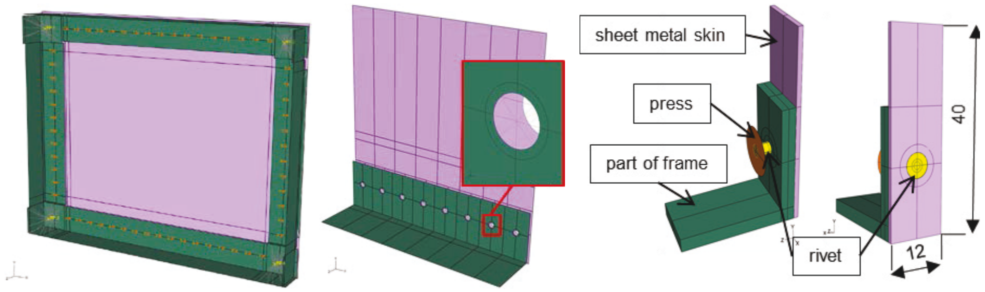
Models, analysis approach methods

Three working models were prepared for the purpose of carrying out the task (Fig. 2):

Model A – is a shell model of the structure using a simplified method of modeling of the rivets.

Model B – a local shell model covering a selected portion of the structure where the peak stresses and deformations are expected to come to existence in the area surrounding the riveted joint. The rivet models are represented by beams matched with holes of suitable diameter.

Model C – is a microlocal solid model covering the area affected by the rivet reaction.



Model A Model B Model C

Fig. 2. Models prepared for scrutiny

The prepared numeric models were analyzed for the following conditions:

- analysis of critical forces and buckling form (Model A);
- preliminary estimation of the panel – deformation and general strain-stress condition subject to calculation considering critical force exceeded (Model A);
- rivet closing simulation (Model C);
- analysis of the panel area subjected to the highest burden with consideration given to initial stresses caused by the rivet closing operation (Model B);
- analysis of the strain-stress condition of an individual rivet with consideration given to initial stresses caused by the rivet closing operation but also by those resulting from the tension field (Model C).

The procedures of FEM analyses were carried out in Abaqus software environment. Applied in all procedures were the elasto-plastic material models supported by isotropic kinematic model of material strain hardening phenomenon using approximated multilinear performance characteristics. Models of the materials were based on compression tests. Because of the non-linear nature of the task, the analyses were carried out to the modified Newton's method [1] with due attention paid to large size of the deflections.

Since it was required that preliminary stresses effected by the rivet closing operation [2, 3] had to be considered in the analysis work, simulation of this process was also carried out. Considered in the simulation were multipair contact and non-linear increase of pressure in the contact job.

Summary and Conclusion

When reviewing results of the tests performed on Model A, it has been found that the resilient loss of the coverage stability occurred at approx. 47 per cent of the maximum burden limit. The charge resulted in the tension field coming to existence. Once critical force has been exceeded, considerable deformation of the coverage metal sheet occurred in vicinity of the contact with the framework members. Consideration was given to the following: shearing forces in the rivets, metal sheet torsion angles and bending sag, progress of the relative offset of the metal sheet against inner edge of the angle (in this case the maximum distance reaching as much as 0.15 mm were revealed at the bottom angle), the segment of rivet joint located in the right hand, bottom corner of construction in Fig 3a, has been selected for further analysis work (Model B).

Consequently, simulation of the rivet closing operation of was carried out (Model C). The obtained results provided for introduction of the preliminary stresses to Model B. The burden of Model B consisted of the displacements yielded by the results of analysis of Model A. Results obtained from Model B provided for selection of the rivet under maximum burden. Displacements revealed in the nodes would be used as burden values in the subsequent stage of analysis to Model C.

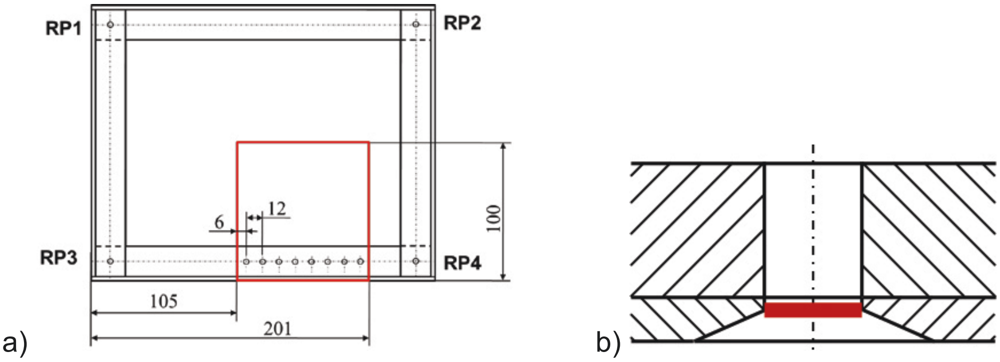


Fig. 3. *a) Dimensions and location of the area selected for further analysis (Model B); b) Rivet joint: marked with color is the zone of maximum pressures and microslips*

The last step of the work consisted in scrutiny of the rivet joint under the highest strain-stress burden in the examined panel. The examination based on analysis of Model C considering information on the preliminary stresses yielded by the simulation of the rivet closing operation. In this case Model C has been used as the sub-model, the boundary conditions for which i.e. displacements have been availed during analysis of Model B.

Displacements were introduced to the second step of analysis (the first step in this model was the rivet closing operation) in the form of the time dependent boundary conditions duly defined on suitable faces of the solid model. They were considered as actual burden resulting from deformation od the shell model.

When scrutinizing the results yielded from analysis of Model C, attention should be paid to stresses in the rivet. It should be noted, that in the results obtained from the second step of the analysis the values of the maximum reduced stresses were practically left intact (490 MPa), but entirely changed their character (see Fig. 4). Considering patterns of the stresses, it can be seen, that the rivet is not only subjected to tension (increase of the stress from 80 MPa to 250 MPa in the rivet shank), but also to bending (note irregular disposition of the stresses.

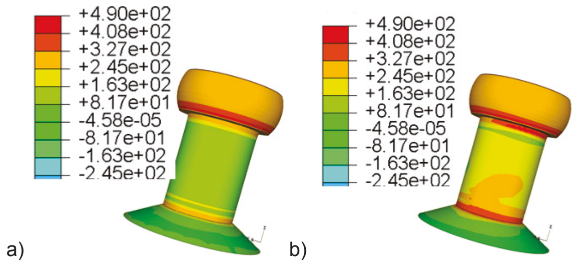


Fig. 4. *Reduced stresses [MPa]: a) resulting from closing of the rivet; b) resulting from closing of the rivet and from introduction of the burden resulting from operation of the tension field*

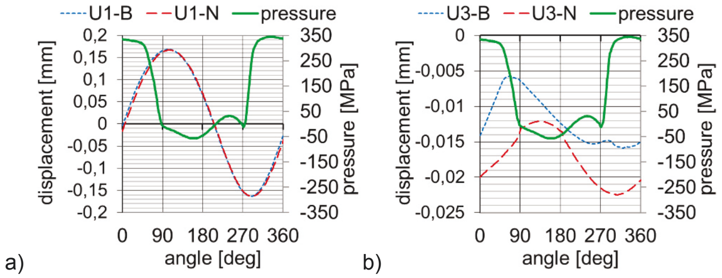


Fig. 5. *Maximum pressures and relative displacements (B – coverage metal sheet, N – rivet): a) circumferential direction, b) center line direction*

When examining relative displacements of matching faces and respective pressures particular attention should be turned to the area marked bold line in Fig. 4b. Within the marked area, the related displacements in both radial and center line directions reached as much as 0.01 mm. Yet, in all three cases the zones of maximum relative displacements correspond with those of the maximum pressures in Fig. 5. It should be noted that the relative circumferential displacements are the smallest and reach no more than 0.003 mm.

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