The effect of rivets application on thermal characteristics of sandwich panel roofings

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INTRODUCTION

Thin-walled cold-formed structures are attractive and economically advisable type of designs. Thin-walled members have some features, which do not permit use of classical methods of analysis of steel structures. Small thickness and non-symmetrical shape of thin-walled profiles cause local buckling of their flanges and webs, restrained torsion [1] accompanied by warping and distortion of member cross-section [2, 3].

Many researchers have studied their stress-strain state under different load conditions and on the development of new types of structures and engineering methods of analysis [4, 5].

Thin-walled cold-formed purlins are typically used as load bearing elements in the roofing of modular buildings [6]. Sandwich panels or layered roofs made of trapezoidal sheeting make up the building envelope. Sandwich panels are usually fastened to purlins by self-drilling screws. Screws permeate an insulation layer of sandwich panels and conduct heat through the sandwich panel, so the screws may be considered as “cold bridges”. Besides application of screws complicates waterproofing measures of roofing because of through holes in sandwich panel.

From the viewpoint of estimating the load-bearing capacity of connection between sandwich panel and purlins with screws, such a solution has also some negative features. Roofing structures experience alternating loads such as negative wind pressure and temperature load. Load of variable direction loosens impermeability of connection and its deformability increases. Then sandwich panels cannot be taken into account in analysis of purlin load bearing capacity directly as it is recommended in Eurocode 3 [7]. Some reduction factors need to be introduced in currently applied design methods to take above mentioned adverse factors into consideration.

Besides, moisture penetrates through the gaps in panel sheeting around screws, in winter it freezes and reduces the thermal and mechanical characteristics of roofing. Certain difficulties take place as well in the course of roof structure installation. As the screws are inserted from the outside and permeate through the thickness of sandwich panel, they can deviate from the set final position on the top flange of purlin. This factor also affects the load bearing capacity of connection and of purlin itself.
The mentioned negative factors make it necessary to develop some new constructive solutions to avoid them. The application of blind rivets may be one of possible solutions [8]. The blind rivets are well-known kind of fasteners used on a level with screws in the connections of cold-formed elements [9]. In the considered application the blind rivets connect the inner sheet of sandwich panel to the top flange of purlin. Fastening of sandwich panels by rivets is carried out from within the building and rivets can be installed strictly in design position. Blind rivets do not destroy insulation layer of panel and improve its thermal characteristics.

But the blind rivets application has also several negative aspects. In case of wind uplift action the adhesion between the insulation layer and inner sheeting of the panel nearby connection can be broken and the bearing capacity of connection at this moment nearly exhausts. So this type of connection may be allowable only for sandwich panels with polyurethane core, as it has a high level of adhesion to sheeting of panel. Another negative factor in application of rivets lies in the inability to check the quality of the formation of rivet head and so the quality of connection. However, despite the mentioned shortcomings rivet connections are worthy of consideration and will be discussed in this paper.

**METHODS**

Two similar roofing structures with self-drilling screws and blind rivets as fasteners were considered. Sandwich panel SPC120/80PU with polyurethane core of thickness 120 mm (coefficient of thermal conductivity $\lambda=0.05$ W/(m$^2$·°C)) with sizes 600x1000 mm was fastened to Ruukki Z-purlin 200x2 (height 200 mm, thickness 2 mm).

In the first case, self-drilling screws ($\lambda=58$ W/(m$^2$·°C)) fasten sandwich panel to purlin in each corrugation (Figure 1). In the second case 5 rivets installed with equal pitch along sandwich panel were used (Figure 2).

![Figure 1. Considered system with screw fasteners](image-url)
Numerical thermal analysis of considered systems was performed with the use of the computer programs MSC.NASTRAN and TEPL. Both programs allow carrying out the analysis of three-dimensional temperature fields in structure.

The algorithm implemented in program TEPL is based on the methods given in [10]. Beside the temperature distribution in structure the value of thermal resistance is received in result of numerical analysis performed with TEPL. MSC.NASTRAN does not allow obtaining automatically the value of thermal resistance.

Finite-element model of roofing system created in MSC.NASTRAN is shown on Figure 3.

The temperature of indoor air assumed was +18 °C and of outdoor air -30 °C. Heat exchange on boundary surfaces of air was taken into account by setting convection coefficients on these surfaces. Heat transfer factor on the surfaces bordering indoor air (surface of purlin and inner face of sandwich panel) was set $a_{in}=8.7$ W/(m²·°C) and on the surfaces bordering outdoor air (corrugate face of panel) it was set $a_{out}=23$ W/(m²·°C).
RESULTS

The values of thermal resistance of two investigated systems are represented in Table 1. It shows that the thermal resistance of roof made with the use of self-drilling screws was about 9% lower than the one with the use of rivets.

Table 1: Comparison of thermal resistance values of structures made with the use of screws and rivet

<table>
<thead>
<tr>
<th></th>
<th>$R_0$, $(m^2 \cdot \circ C)/W$</th>
<th>The relative difference</th>
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<tr>
<td>Self-drilling screws</td>
<td>1.6734</td>
<td></td>
</tr>
<tr>
<td>Blind rivets</td>
<td>1.8188</td>
<td>8.7%</td>
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</table>

The contour plots of temperature distribution in the structure obtained from the numerical analysis with the use of MSC.NASTRAN and TEPL are represented below (Figures 4 and 5). Heat flow is going out of building through the screws. It is clearly seen in Figure 4. The temperature of inner face of sandwich panel (Figure 5) is lower when screws are used.

The value of thermal resistance was calculated also manually based on the recommendations of Russian building standards and rules SNiP “Thermal performance of the buildings.

Cold bridges such as screws cannot be taken into account in manual analysis based on SNiP recommendations. There exists a procedure for obtaining the value of thermal resistance taking into account point inhomogeneity of insulation layer but this procedure requires the results of analysis of three-dimensional temperature field. This procedure was automated in program TEPL.

So manually the analysis was carried out without taking into account cold bridges in sandwich panel insulation layer. In the Table 2 the comparison of the thermal resistance values of structures made with the use of screws obtained in program TEPL and manually by methods of SNiP “Thermal performance of buildings”.

As show the table data the thermal resistance obtained manually without taking into account screws as cold bridges are higher at about 13% than those based on numerical analysis.
Figure 4. Comparative contour plots of temperature distribution in cross-section of sandwich-panel fastened to purlin with the use of:

a, b – screws (a-MSC.NASTRAN; b-TEPL);
c, d – rivets (c-MSC.NASTRAN; d-TEPL)
Figure 5. Comparative contour plots of temperature distribution on the inner face of sandwich-panel fastened to purlin with the use of:
a, b – rivets (a-MSC.NASTRAN; b-TEPL); c, d – screws (c-MSC.NASTRAN; d-TEPL)
Table 2: Comparison of the thermal resistance values of structures made using screws obtained in program TEPL and manually by methods of SNIIP “Thermal performance of buildings”

<table>
<thead>
<tr>
<th>Numerical analysis</th>
<th>Manual analysis</th>
<th>The relative difference</th>
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<tr>
<td>1,6734</td>
<td>1,8877</td>
<td>12.8%</td>
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CONCLUSIONS

As a result of carried out analysis the following conclusions can be drawn:

1. Self-drilling screws as cold bridges decrease considerably the thermal resistance of roofing and should be taken into account in thermal analysis.
2. The rivets allow achieving higher values of thermal resistance.
3. Though the overall replacement of penetrating fasteners by rivets does not seem to be likely it is still possible to reduce the proportion of them in panel to purlin connections thus reducing the heat losses.

REFERENCES