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MPA **MPA Stuttgart**
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Material Testing Institute of the University of Stuttgart

Test Report

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Test Subject:	**Testing of Clamping Connections for Fastening Solar Modules and Snow-Catcher Installations**
Test Specification:	DIN EN 10002-1, DIN EN ISO 898, DIN 18800, DIN V 4113-3, DIN EN 1990, DIN 1999-1-1, DIBt-Permit Z-30.3-6
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1. Objective

The firm SM-Befestigungssysteme [SM-Fastening Systems] GmbH, 71634 Ludwigsburg, produces and sells, among other things, clamping connectors ("SM-Klemmfaust [SM-Clamping Fist]") for fastening solar modules and snow-catcher devices to double-seam roofs. According to the company, EU Patent 0 594 948 was issued for these clamping connectors (in this connection, see Figs. 1 to 3, Enclosures 1 and 2).

Fastening of double-seam roofs to the roof structure located underneath it in general takes place in accordance with the specific rules of tinsmith technology (see Figs. 4 and 5 of Enclosures 3 and 4).

Experimental studies regarding the usefulness of the produced clamping connectors for solar modules and snow-catcher devices are not yet available at present.

For this reason, by letter of September 8, 2009 the firm SM-Befestigungssysteme GmbH commissioned the Material Testing Institute (MPA) of the University of Stuttgart to perform the required preliminary tests of the clamping connections, in particular between the "SM-Klemmfaust [Clamping Fist]" and the aluminum elbow seam roof and to represent the results in a test report.

Tests regarding corrosion protection of the structure, as well as regarding other elements of support structures, were not part of the commission of MPA Stuttgart.

2. Documentation

For processing the commission, the Material Testing Institute, Stuttgart, had the following documents available:

/1/ Schematischer Aufbau der Klemmverbindung [Schematic Structure of the Clamping Connection] (Fig. 3, Enclosure 2)
/2/ Fachregeln für Klempnertechnik [Technical Rules for Tinsmithing Technology], Ed. 10/98/ (Figs. 4 and 5, Enclosures 3 and 4).

3. Tests Performed

The clamping connection employed in the tests ("Clamping Fist Made of Aluminum", item no. SM-KAS without aluminum angle pieces) consisted of the following elements:
- aluminum profile from EN AW - 6060 T66
- flat round screws with square lug DIN 603 - M12 x 35 A2-70
- washer ISO 7089 - A2θ13 (DIN 125 A)
- hex nut DIN 934 - M12.A4-80 and
- straight pin ISO 2338 - 4 x 7 - A1

The tests of the clamping connections were performed on aluminum double-seam roof elements, which were provided to MPA Stuttgart by SM-Fastening Systems GmbH.

In this case the seam roof elements consisted of a glued wood plate of the dimensions 26x620x1000 (mm), on which two sliding holders (Item No. SM-Ese25), each with 3 cross-recess hex screws 4x20 (mm) A2, were fastened at a spacing of 500 mm and centered in the longitudinal direction of the plate. The roof skin elements were arranged on both sides next to the common axis of the sliding holders, so that the double fold was located centered above the sliding holders.

In all tests, AlMn1Mg0.5 H41 in accordance with DIN EN 573 / DIN EN 1396 (FALZONAL(R) NOVELIS WG-C4S) of a thickness of 0.7 mm was employed as the roofing material (roof skin).

Here, the visible side of the FALZONAL roof skin consisted of a brown PVdF layering system. The thickness of the lacquer layer is reported by the manufacturer to be between approx. 25 to 40 μm. The height of the elbow seam was approx. 25 mm.

By means of the tests described here it was initially intended to show proof that in case of stress at right angles in respect to the roof skin the clamping connections made would at least attain the stretch value of 560 N (as measured resistance value) mentioned in Section 9.6.1 of /2/.

For this reason, in the tests performed, steel angle pieces were clamped over the test body on both sides next to the elbow seam in order to experimentally detect only the displacement of the clamping connection ("clamping fist") in relation to the roof skin (Graphs 6 and 7, Enclosure 9).

Because of the materials employed (aluminum alloy, screws, washers and nuts) the tightening moments M_A listed in DIN 18800-7 for screw connections could not be used.

To determine the required tightening moment M_A it was therefore first necessary to experimentally determine for the screws used the connection between tensile force and screw elongation in the elastic range in accordance with DIN EN ISO 898.

Thereafter, an instantaneous screw elongation characteristic was determined from sample elements. From the combination of both graphs, the required bias force F_V and the associated tightening moment M_A were determined for the elastic stress range.

Furthermore, sliding load tests were performed with three test bodies each in the X- and Y-axes of the Al- profile. Differing from the representation in photo 3 in Enclosure 2, the clamping connections with the cylinder pin side were arranged on the side opposite the double fold. Thus, this arrangement of the clamping connection on the double fold corresponds to the embodiment represented in Fig. 2 (Enclosure 1). Moreover, washers ISO 7089 - A2-Θ13 were arranged underneath the nut in order to assure a defined frictional correction value between the underside of the nut and the washer.

The results were represented in graphs and tables.

4. Test Results

- Preliminary Tests for the Conversion of the Tightening Moment into Bias Force

Initially, in accordance with DIN EN ISO 898, a tensile force screw elongation characteristic was recorded for three screws of the previously mentioned flat round screws with square lug (DIN 603 - M12x35 A2-70) of the clamping connection (see Graph 1, Enclosure 5), and an instantaneous screw elongation characteristic was determined for the clamping connection. No additional lubrication of the screws, washers and nuts was provided here. The bias forces F_V in connection with the associated tightening moments M_A were calculated from the combination of the two graphs and represented in Table 1 of Enclosure 6, as well as graphically represented in Graph 2 of Enclosure 6.

In connection with further tests of the clamping connection it was decided to apply a tightening moment M_A = 75 Nm, taking into consideration the surface pressure occurring under the washer.

- Transverse Load Tests at Right Angles to the Roof Skin

Transverse load tests (V2 to V4) at right angles to the roof skin (in the X-axis of the Al-profile in accordance with EC 9) were performed on three test bodies in order to determine the sliding load F_G with the associated displacement. The test apparatus can be seen in Graphs 6 and 7 of Enclosure 9. The connection to the tension straps was made in such a way that no additional clamping force occurred. In all graphs, the displacement of the Al-profile is shown reduced by the displacement of the roof skin.

Test 1 had to be stopped prematurely, since no centered force introduction into the Al-profile was achieved with the test installation, so that an oblique tension was introduced into the clamping connection.

The test results of tests (V2 to V4) are represented in Graph 3 of Enclosure 6. The various individual results can be found in Graphs 4 to 6 (Enclosures 7 and 8).

The force displacement curves in all graphs have an irregular appearance. This is a result of the ball-shaped scanning surface of the travel sensor and of the radius-shaped surface of the Al- profile, or in other words of the double fold. Following EC 9, the sliding loads were determined from the graphs at a displacement Δl = 0.15 mm.

In connection with the sliding load test 2 it appears that in the course of installing the sample the travel sensors WA 2 and WA 4 had obviously not been sufficiently correctly placed, which can be seen from a jumping course of the curves in the graph.

Therefore only the displacement of travel 1 - travel 3 was considered for the evaluation.

In accordance with EC9, the sliding loads were determined from the graphs at a displacement of Δ l = 0.15 mm.

The following sliding loads F_{GVi} where achieved in the course of individual tests:

Table 1

Consec. No.	Test No 1	Displacement WA 1 (mm) 2	Sliding Load F_{GVi} (kN) 3
1	V2	0.15	3.10
2	V3	0.15	4.91
3	V4	0.15	4.89
4	Mean value $\bar{x}$	-	4.30
5	Deviation s	-	1.04
6	5% fractile value	-	0.80

Because of the small number of tests and the large deviation of the measured values, the 5% fractile value of the sliding load at right angles in respect to the roof skin resulted as F_{GV5} = 0.8 kN. Calculation of the fractile value was performed in accordance with DIN EN 1990, Annex D, with standard deviation unknown.

The appearance of the samples V2 to V3 at the end of the tests can be seen in Figs. 8 to 10 of Enclosure 10.

- Transverse Load Tests Parallel with the Al-Clamping Profile

Transverse load tests (V2 to V4) were performed on three test bodies parallel with the

Al clamping profile (in the X-axis of the profile in accordance with C9), with the force introduced in the screw axis. The test apparatus can be seen in Figs. 11 to 14 of Enclosures 13 and 14. Connection with the tension straps was designed in such a way that no additional clamping force occurred. Test V1 was used for checking the measuring apparatus.

The results of tests V2 to V4 are represented in Figs. 7 to 9 (Enclosures 11 and 12).

In accordance with EC9, the sliding loads were determined from the graphs at a displacement of Δ l = 0.15 mm.

The following sliding loads F_{GVi} where achieved in the course of individual tests:

Table 2

Consec. No.	Test No. 1	Displacement WA 1 (mm) 2	Tension Displacement WA 2 (mm) 3	Sliding Load F_{GVi} (kN) 4
1	V2	0.15	0.354	3.47
2	V3	0.15	0.000	2.85
3	V4	0.15	0.207	2.63
4	Mean value $\bar{x}$	-	-	2.98
5	Deviation s	-	-	0.43
6	5% fractile value	-	-	1.53

As can be seen from the displacement values of the travel sensor WA2 in connection with tests V2 and V4 in Table 2, the moment of eccentricity resulting from the offset between the screw axis and the center of the clamping surface causes a drifting force. This displacement could not be detected in connection with test V3.

As can be seen from the results of test V2, the displacement WA 2 (at right angles in respect to the roof skin) can become relatively large in comparison with the sliding travel (WA1).

The 5% fractile value of the sliding load in connection with a displacement Δl = 0.15 mm was determined to be F_{GX5} = 1.53 kN. The calculation of the fractile value was performed in accordance with DIN EN 1990, Annex D, with unknown standard deviation.

In the present case, the characteristic value of the resistance R_K in accordance with DIN EN 1999-1-1 corresponds to the determined 5% fractile value x_5 of the respective resistance.

In accordance with DIN EN 1999-1-1/A1: (draft), the measuring resistance R_d is calculated as

$$R_d = \frac{R_K}{\gamma_{M,i}}$$

In accordance with section 3.2.1 (2) of the General Building Inspection permit Z-30.3-6 of April 20, 2009, it is not permitted to regularly pre-stress rust-resistant screw connections, so as to avoid possible appearances of creep in case of stresses due to tension.

Therefore, in connection with the measuring resistance R_d, MPA Stuttgart recommends to increase the partial safety correction value $\gamma_M = 1.25$ for proving the safe bearing capacity by 10% in order to take these material properties of the rust-resistant screw connections into consideration. Thus, for proving the safe bearing capacity, the result is $\gamma_M = 1.25 \bullet 1.1 = \underline{1.375}$.

Thus, the measuring resistance R_d for stresses at right- angles in respect to the roof skin, the following applies:

$R_d = 0.8/1.375 = 0.58$ kN.

To the extent that the measuring resistance for a simultaneously acting transverse stress parallel in respect to the Al profile (in the direction of the X-axis in accordance with EC9), and the transverse stress at right angles to the roof skin (in the direction of the Z-axis of the profile in accordance with EC9) must be determined, this can take place with sufficient assurance by a straight-line interaction between the measuring resistances and the transverse resistances in the X- and Z-axes of the Al profile.

5. Summary

For demonstrating the suitability, tests regarding the interaction between the tightening moment M_A and the bias force F_V, as well as transverse load tests were performed on the clamping device ("SM-Klemmfaust" [Clamping Fist]) mentioned in section 3 of this report.

Based on the results of these tests, it was determined by MPA Stuttgart that of the tested clamping connections, when stressed at right angles in respect to the roof skin (in the Z-axis of the Al profile in accordance with EC9), the calculated measuring resistance R_d attained the value of 0.56 kN mentioned in /2/ with the recommended assurance, if the statements below apply and the set requirements are met:

- The users of the clamping connections produced by SM-Befestigungssysteme GmbH (SM-Fastening Systems GmbH), 71634 Ludwigsburg, DE, must prove by means of a static calculation that the measured resistances of the clamping connection between aluminum profile and standing fold roof calculated with the recommended safety factors from the measured characteristic resistance values are greater than the measured values of the effects.

- The clamping connections must be prestressed with the tightening moment M_A = 75 Nm. In accordance with Section 8.5 of DIN V 4113-3:2003-11, the clamping connections must be re-tightened with a tightening moment M_A = 75 Nm after 72 hours at the earliest.

- No additional lubrication of the screws, washers and nuts should be provided. Prestressing must take place via the nut. Moreover, the user must employ calibrated tightening devices for prestressing.

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