Pull-Out Strength of Self Tapping Fasteners in Aluminum Screw Slot Connections

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Introduction

A screw slot (sometimes called a screw boss by extruders) is a semi-hollow in an aluminum extrusion intended to retain a screw parallel to the axis of the member. Examples of different extrusion profiles with screw slots are shown in Figure 1. Screw slots are often used to connect aluminum extrusions in a variety of structures including architectural applications, curtain walls, and window and door frames. Self-tapping screws are used in conjunction with screw slots, and are typically stainless steel or aluminum. Aluminum screws are typically 2024-T3 or 7075-T73. Stainless screws are generally 300 or 400 series. The screws may be thread cutting or rolling and may have spaced or machine threads.

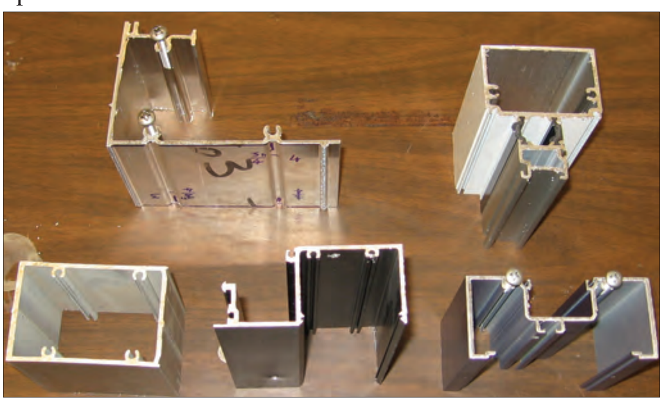

Figure 1. Several extrusion profiles used in the study.

Standard screw slot dimensions for aluminum extrusions are shown in the *Aluminum Design Manual (ADM)*,[1] and are shown in Figure 2. Screw slots may be located along one of the extrusion walls or in a corner where two walls intersect. Common or standard screw slots are not closed, and have openings that vary from 62° to 70°.

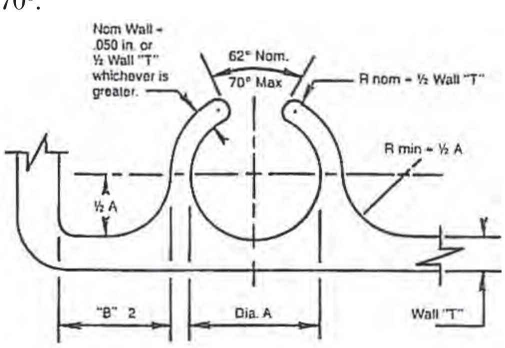

Figure 2. Standard aluminum screw slot.[1]

The purpose of this study was to test and evaluate the pull-out strength of aluminum screw slot connections. Six different extrusion profiles were supplied by four manufacturers. A majority of the profiles tested were 6061 and 6063 alloys, although a limited number of 6061-T6 extrusions were made available. Each manufacturer supplied coated steel or stainless steel screws for the given screw slot geometry. Nominal dimensions of the screw slots provided were close to the standard screw slot dimensions given in the *ADM* (Table I). Screw embedment length varied from 6.35 mm (0.25″) to 38.1 mm (1.5″). Three nominal screw diameters were used, and included No. 10 (4.83 mm or 0.19″), No. 12 (5.49 mm or 0.216″), and 6.35 mm (0.25″). All of the extrusions tested had screw slots located on a wall; no corner screw slots were tested. A total of 79 tests were conducted, data evaluated, and a predictive model developed. To determine the ultimate strength of the extrusions, tensile tests were conducted for each profile.

Shape	Shape ID (in.)	ADM ID (in.)	Shape Opening Angle (deg)	ADM Opening Angle (deg)
A	0.188	0.19	60	62 to 70
B-M	0.189	0.19	60	62 to 70
B-N	0.17	0.169	59	62 to 70
C	0.228	0.228	60	62 to 70
D-1	0.228	0.228	62	62 to 70
D-2	0.228	0.228	62	62 to 70

Table I. Screw slot dimensions.

Background

Six different extrusion profiles were supplied in lengths from 457 mm (18″) to 914 mm (36″). Extrusions were saw cut into convenient 150 mm (6″) lengths. Screws were inserted into the slots to a prescribed embedment length on one end of each 6″ long specimen. Another screw was placed into the slot on the other end of the 150 mm (6″) length and run into the slot until just enough of the screw head protruded to grab in the fixtures. Load was applied to the screws until the fastener pulled out of the slot. A total of 79 tests were conducted, as summarized in Table II.

Shape	Alloy-Temper	Embedment Length (in.)	Number of Tests
A	6063-T5	0.5	4
A	6063-T5	1	4
A	6063-T5	1.125	3
A	6063-T5	1.5	4
B-M	6063-T5	0.25	4
B-M	6063-T5	0.375	6
B-M	6063-T5	0.5	6
B-N	6063-T5	0.25	4
B-N	6063-T5	0.375	4
B-N	6063-T5	0.5	4
C	6063-T5	0.5	4
C	6063-T5	0.75	4
C	6063-T5	1	4
D-1	6061-T6	0.5	4
D-1	6061-T6	0.75	4
D-1	6061-T6	1	4
D-2	6063-T5	0.5	4
D-2	6063-T5	0.75	4
D-2	6063-T5	1	4

Table II. Summary of screw slot tests.

Grips were fabricated for screw slot testing, as shown in Figure 3. Each grip consisted of a rectangular hollow structural tube. On one side of the tube, a slot was milled and a plate inserted into the slot. Each plate was secured to the tube through a pin, and was secured to the testing machine through conventional wedge action grips. An elongated hole was drilled in the opposite side of the tube, and a slot milled from the edge of the hole. The

Figure 3. Grips used for securing screw heads.

hole and slot were used to secure the self-tapping screws. A typical setup for a pull-out test is shown in Figure 4. For each screw slot tested, load and crosshead displacement were measured.

Figure 4. Test set-up.

In addition to tests for pull-out strength, tensile coupons were cut from flat elements of each extruded profile. Coupons were machined into standard 2″ gauge length tensile samples. Each specimen was tested in tension, with both load and strain continuously recorded. From the load-strain data, yield and ultimate strengths were determined according to accepted standards.[2] The average ultimate strengths obtained from the tensile tests are summarized in Table III.

Shape	Average Tensile Ultimate Strength (psi)
A	33,990
B-M	35,350
B-N	25,630
C	33,090
D-1	44,120
D-2	32,730

Table III. Summary of extrusion tensile strength.

Experimental Results and Data Analysis

Test failures occurred by opening of the screw slot. In no case did the fastener rupture in tension. Average test results are summarized in Table IV. While 79 tests were conducted, there were 19 different test configurations. A test configuration included samples of the same extrusion material, fastener type, and embedment length. Average failure loads as a function of embedment length for each combination of extrusion material and fastener size are presented in Figures 5-8. Each point represents an average of at least three or more tests. In each case, a best-fit line was found by regression analysis and is included on Figures 5-8. Quality of fit parameters were calculated and varied from 0.93 to 0.98.

D Screw Diameter in.	L Embed Length in.	F_{tu} Extrusion Strength psi	L/D	P_t Tested Pull-Out lb	P_p Predicted Pull-Out lb	P_p/P_t
0.216	0.5	33,990	2.31	924	1065	1.15
0.216	1	33,990	4.63	2251	2129	0.95
0.216	1.125	33,990	5.21	2483	2395	0.96
0.216	1.5	33,990	6.94	2888	3194	1.11
0.216	0.25	35,350	1.16	344	554	1.61
0.216	0.375	35,350	1.74	780	830	1.06
0.216	0.5	35,350	2.31	1074	1107	1.03
0.190	0.25	25,630	1.32	343	353	1.03
0.190	0.375	25,630	1.97	624	530	0.85
0.190	0.5	25,630	2.63	923	706	0.77
0.250	0.5	33,090	2.00	1124	1200	1.07
0.250	0.75	33,090	3.00	1990	1799	0.90
0.250	1	33,090	4.00	2747	2399	0.87
0.250	0.5	44,120	2.00	1273	1599	1.26
0.250	0.75	44,120	3.00	2113	2399	1.14
0.250	1	44,120	4.00	2867	3199	1.12
0.250	0.5	32,730	2.00	1048	1186	1.13
0.250	0.75	32,730	3.00	1872	1780	0.95
0.250	1	32,730	4.00	2523	2373	0.94
			total =	19	average =	1.05

Table IV. Average test results.

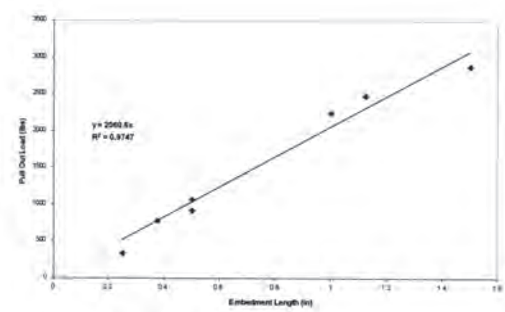

Figure 5. Pull-out test results for 6063-T5 screw slots with No. 10 screws.

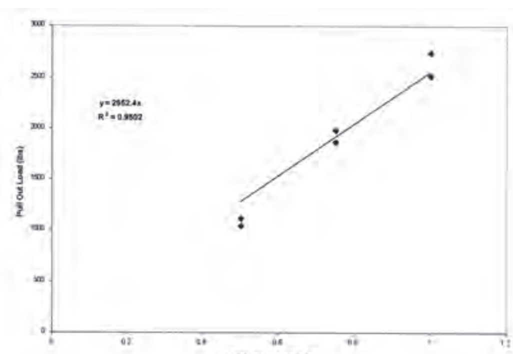

Figure 6. Pull-out test results for 6063-T5 screw slots with 1/4″ diameter screws.

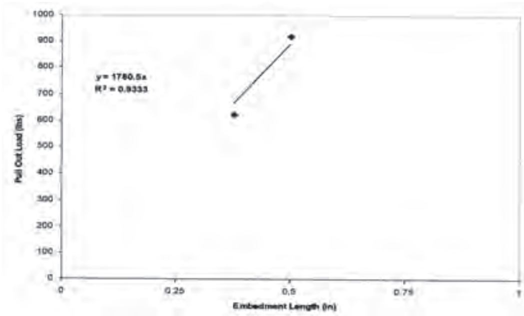

Figure 7. Pull-out test results for 6063-T5 screw slots with No. 8 screws.

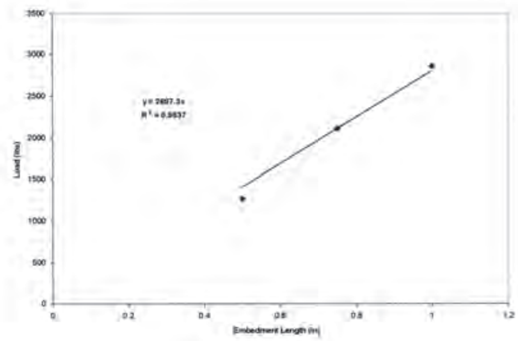

Figure 8. Pull-out test results for 6061-T6 screw slots with 1/4″ screws.

The average pull-out loads for each of the 19 test groups, divided by the product of the embedment length, screw diameter, and ultimate strength are presented in Figure 9. An average value for the ratio was found to be 0.29. The data is generally well grouped, with the largest outlier resulting from the shortest embedment length relative to fastener diameter or L/D = 1.16.

From the data analysis, a predictive model for pull-out strength is proposed as:

$$P = 0.29DLF_{tu}$$

Where:
P = the predicted pull out strength
D = nominal diameter of the tapping screw
L = screw embedment length
F_{tu} = tensile ultimate strength of the extrusion

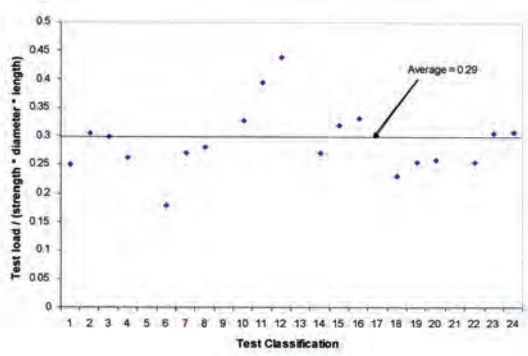

Figure 9. Analysis of average test data.

The variation in the predicted load as determined by the equation as compared to the actual test load is depicted in Figure 10. A perfect fit would result in all test results falling on the predicted line. None of the predicted strengths, with the exception of the embedment length

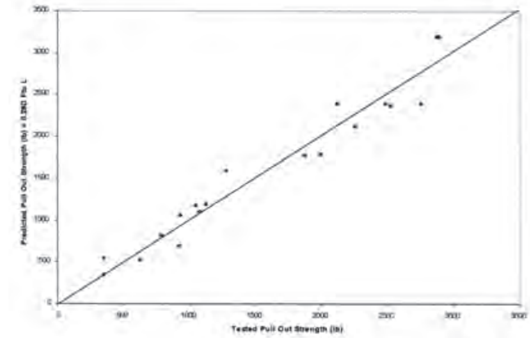

Figure 10. Predicted pull-out strength compared to test results.

to screw diameter of 1.16, exceeded the test strengths by more than 15%.

Conclusions

For 79 tests of three screw slot sizes, three alloy tempers, six extruded shapes, and embedment lengths from 1.16D to 6.94D, the average pull-out strengths of screws in the *ADM* slots is $P = 0.29DLF_{tu}$. Furthermore, the pull-out strength of short embedment lengths of less than two diameters may vary significantly from the average predicted strength.

References

1. *Aluminum Design Manual 2005: Specifications and Design Guidelines for Aluminum Structures*, The Aluminum Association, Washington, DC, 2005.

2. ASTM Standard B 557, 2006, *Standard Test Methods for Tension Testing Wrought and Cast Aluminum and Magnesium Alloy Products*, www.astm.org.

Dr. Craig Menzemer *is an associate professor of Civil Engineering and serves as an assistant dean for Graduate and Undergraduate Studies at The University of Akron within the College of Engineering. Dr. Menzemer is the author or co-author of over 40 technical articles and a professional reference guide, called* Fatigue Design of Aluminum Components and Structures. *Prior to joining The University of Akron, Dr. Menzemer was employed as a technical specialist at the Alcoa Technical Center. He obtained a Ph.D. in civil engineering at Lehigh University in 1992 with fatigue and fracture of structural components as the primary area of study.*

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J. Randolph (Randy) Kissell *co-founded the TGB Partnership, an engineering firm specializing in aluminum structures in 1993 and has been involved in the design, fabrication, and erection of aluminum structures since 1978. He co-authored* Aluminum Structures - A Guide to Their Specifications and Design, *published by John Wiley and now in its 2nd edition, and co-holds two US patents for aluminum structures. Kissell is the secretary of the Engineering Advisory Committee of The Aluminum Association, responsible for the Specification for Aluminum Structures, used throughout the U.S. for aluminum structural design. He is also secretary of the American Welding Society's Subcommittee on Aluminum Structures and a member of the ASTM Light Metal Alloys committee, the Canadian Standards Association's committee on Strength Design in Aluminum, the American Petroleum Institute's Aboveground Storage Tank committee, and the American Society of Civil Engineers Load Standards Committee.*