Behavior of Armatherm FRR Thermal Break Material in Moment Connections

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August 2015

Introduction

One approach to eliminating some thermal bridge areas in steel and concrete buildings is the use of material which causes a thermal break within the building envelope. Fiber-reinforced resin (FRR) material is inserted within beam-to-beam or beam-to-column connections to prevent thermal bridging between interior and exterior elements. A common configuration that benefits from thermal barrier plates is the connection of exterior balcony supports to interior columns, which requires a moment-carrying connection. Another potential location for thermal barrier plates is behind the shelf angles that support exterior brick or block veneers, which only requires a shear connection.

Thermal break materials used in these applications are considered filler plates in the U.S. and European design codes. The AISC code[1] section J5 requires a reduction in the shear strength of the bolts in the connection in the presence of filler greater than 1/4 in thick. Prior to the 2010 Code, this approach was limited to fillers up to 3/4 inch. As two alternatives to the bolt shear strength reduction, fillers may be made continuous with one of the connecting elements by enlarging the filler and securing it with additional bolts. An additional approach is to design for a slip-critical connection. European codes[2] also specify a shear strength reduction of the bolts, and also the filler to 25 mm (1 inch) for the 19 mm (3/4 inch) bolt commonly used in building construction. Thermal break materials are often specified to be 1 or 2 inches in thickness.

Research has been conducted to evaluate the effect of thermal break components on their overall heating and cooling load on a building[3]. However, relatively little research has been published on the effect of thermal barrier material on the mechanical behavior of structural connections. Oostdyk, et al., investigated the behavior of an FRR pad between clamped plates, as characterized by the loss of tension in the clamping bolts over time[4]. The FRR pad was found to not cause any additional time-dependent losses of clamping force beyond the relaxation that occurs in an all-steel bolted connection. In fact, losses in configurations with FRR pads were actually slightly smaller than the all-steel configurations. This was attributed to the longer bolt lengths used for the configurations with FRR thermal break material. Cleary and Riddell evaluated behavior of shear connections with thermal break material[5]. The FRR material was found to have a lower coefficient of friction compared to steel. However, a high friction surface FRR material in a coefficient of friction equal to or greater than that of steel.

The purpose of this study is to evaluate the behaviors of moment connections that include FRR thermal break material. Results are presented in the context of the performance of all-steel connections.

Experimental Procedure

Materials

Thermal break material manufactured from a close woven, E-glass fabric reinforcement, impregnated with a high purity, low conductive, thermosetting resin were used for the tests discussed in this report. Two grades of FRR material were evaluated: standard weave and high weave. In the United States, these materials are available in 0.5-inch, 0.75-inch, 1-inch and 2-inch plates. This study tested FRR plates of 1.0-in and 2.0-in. Physical, mechanical, and thermal properties for both grades of FRR material are summarized in Table 1.

Table 1. Pertinent properties of thermal plate materials[6, 7]

	Value		Units
Property	**Standard Weave**	**High Weave**	
Maximum Loading Stress	42.3	50.0*	ksi
Strain at Maximum Stress	3%	3%	
Compressive Modulus	673.4	1,000*	ksi
Shear Strength	16.0	16.0	ksi
Standard Thickness	0.5, 0.75, 1.0, 2.0	0.5, 0.75, 1.0, 2.0	inch
Density	83	85	lb/ft^3
Thermal Conductivity	0.17	0.17	$Btu\text{-}ft/ft^2\text{-}hour\text{-}^oF$
Minimum Operating Temperature	-60	-60	^oF
Maximum Operating Temperature	220	220	^oF

*estimated

ASTM A325[8] 0.75-in structural bolts, ASTM A563 Grade C nuts[9] and ASTM F436[10] washers were used in all connections. Both ends of the bolts were faced on a milling machine to provide parallel faces for ultrasonic measurements.

Test Configuration

A schematic of the test configuration is shown in Figure 1, including reaction frame, cantilever beam, and hydraulic jack. The steel end plate is a 6-in x 10-in x 0.5-in plate with four bolt holes spaced 6-in on center vertically and 3-in on center horizontally. Load was applied at one end of the cantilever using a hydraulic jack centered 36-in from the face of the column. Vertical displacements of the beam were measured at the face of the column, at 18-in from the face of the column, and at the loading point. The base of the test configuration consisted of a W10x15 GR 50 beam bolted to a typical stiff reaction frame with four ASTM A325 3/4-inch diameter structural bolts with standard ASTM F436 washers behind the nut. The introduction of FRR pads between the beam and vertical column for each sub-configuration is described in Table 2.

Table 2. Configurations for Moment Testing

Configuration	Filler Material	Thickness	Bolt Length
1	None	N/A	2.25”
2	Standard Weave	1.0”	3.25”
3	Standard Weave	2.0”	4.25”
4	High Weave	1.0”	3.25”

Configuration 1 provided a baseline case of the connection behavior without the presence of a thermal break. Configurations 2, 3, and 4 allow comparisons between varying thickness and grade of FRR thermal break material.

The test procedure began with the bolts being tightened to appropriate loads according to the bolt tightening procedure described in the section below. Then, a vertical load was applied 36-inches from the face of the beam using a hydraulic jack. The load was applied in a cyclic fashion, as denoted in Figure 2. Each configuration was tested using both the high load and low load sequence. Bolt tension was measured at load steps 1 and 6. Displacement gages along the beam recorded total displacement at the load point (36-in from the face of the column) and at the midpoint (18-in from the face of the column.

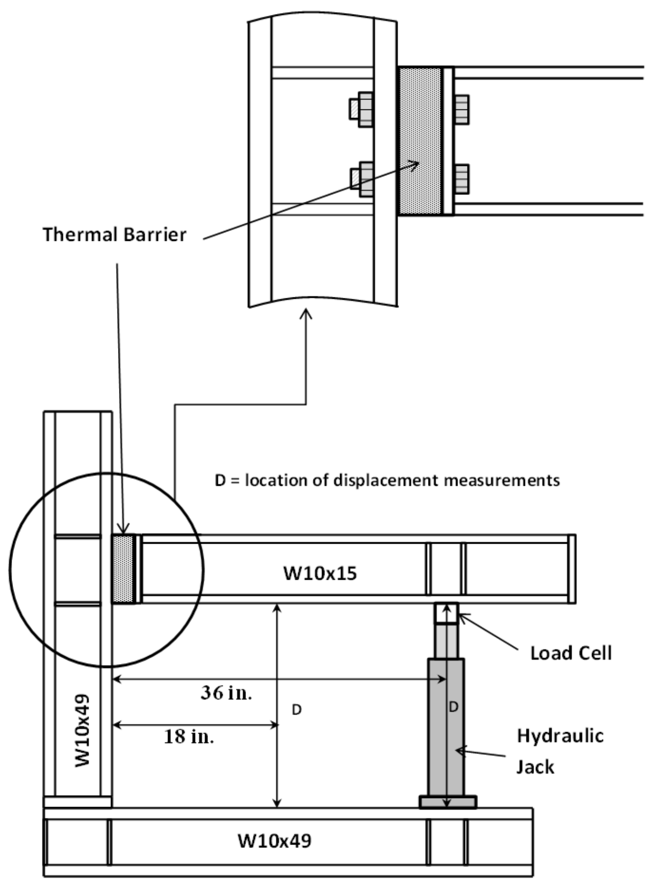


Figure 1. Moment-Rotation Test Set-Up Schematic.

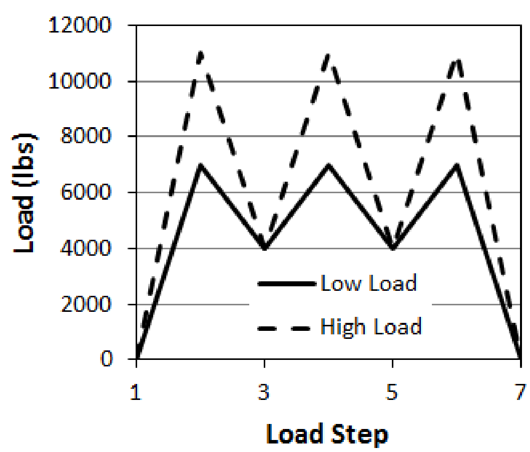


Figure 2. Load sequences used in test program.

Bolt Clamping and Monitoring Procedure

A consistent tightening procedure was used for this testing program. All four 3/4-in diameter structural bolts in each assembly were hand-snugged. Then each bolt was tensioned to approximately 32,200 pounds using the tightening sequence shown in Figure 3. The initial tension of 32,200 pounds is approximately 15% above the RCSC minimum pretension[11] for a slip critical connection. The bolt tension was measured using ultrasonic means[12]. The tension in each bolt was re-measured thirty minutes after initial tightening to determine the total clamping force in the assembly before loading.

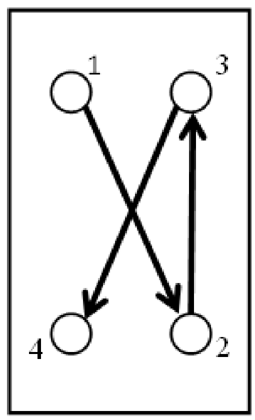


Figure 3. Bolt Tensioning Sequence

Results and Discussion

Joint Stiffness

The load-versus-deflection plot for a representative of each configuration tested is shown in Figure 4. The tests with thermal barrier plates exhibited a small nonlinearity during the first loading cycle. The behavior was linear during subsequent unloading and loading cycles. For a given load, the maximum displacement measured increased relative to an all steel connection with increasing plate thickness and reduction in plate weave. Deflections did not further increase with repeated loading cycles.

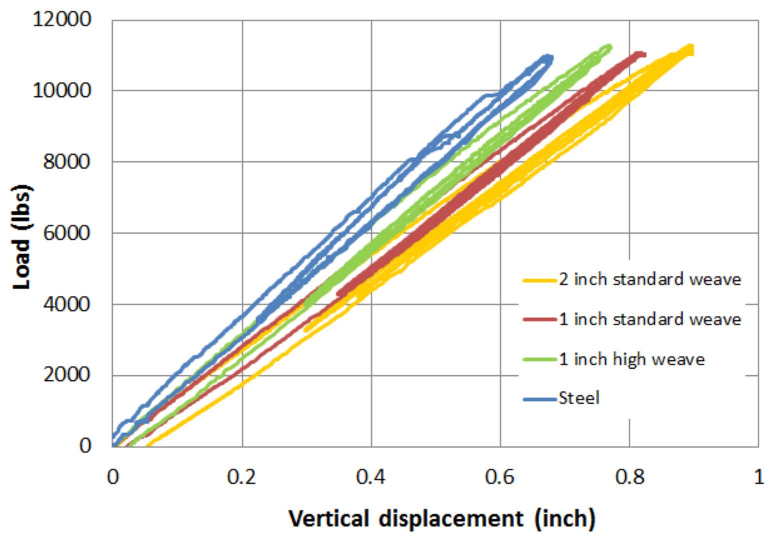


Figure 4. Load versus displacement for representative samples.

The total end deflection of the beam is assumed to result from Timoshenko beam theory deflections of a cantilever beam and a concentrated rotation at the connection. The total flexibility was obtained from the inverse of the slope of the experimentally measured load versus deflection curves, using the portion of the final unloading cycle between 2000 and 6000 pounds. From this total flexibility, the theoretical flexibility of a cantilever beam with a rigid connection – including shear deformation – was subtracted. The remaining flexibility term, attributed to a concentrated rotation at the joint, was then scaled by the length measurement from the connection to the point of loading of the beam to obtain a connection flexibility term with units of rotation in radians per unit applied moment. The resulting flexibilities are plotted in Figure 5 for steel on steel, as well as high weave and standard weave for both 1 inch and 2 inch thicknesses. The linear fit lines in Figure 5 include the steel-only data as zero thickness plates for both standard and high weave cases. The steel connection averaged a flexibility of 5.2×10^{-7} radians/ft-lb of applied moment. Addition of the thermal break material increased the rotation by 4.6×10^{-8} to 6.9×10^{-8} radians/ft-lb per inch of pad thickness incorporated in the connection. The additional rotation attributed to the thermal break pad was an order of magnitude lower than the rotation associated with the base case all-steel connection.

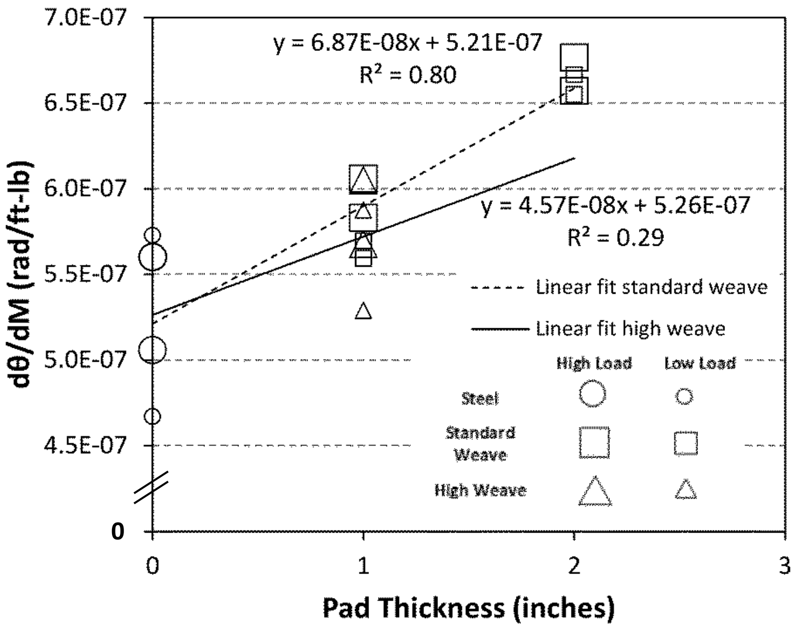
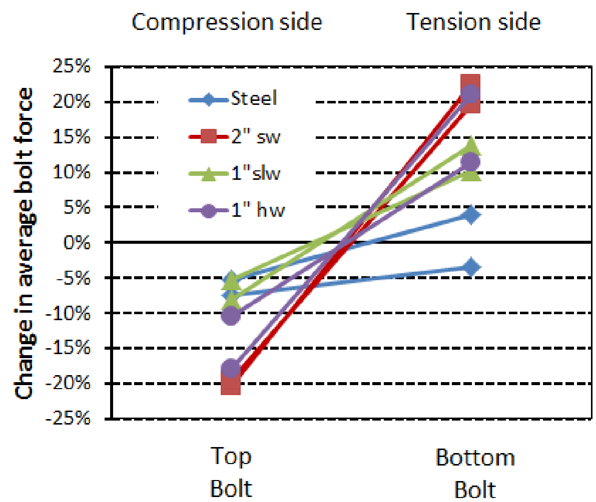


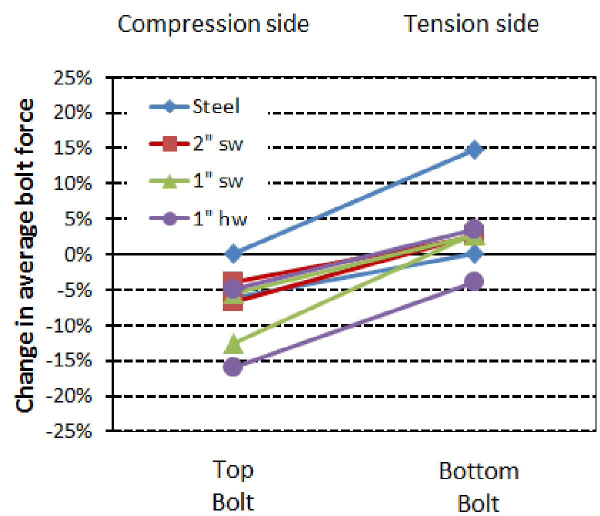
Figure 5. Connection flexibility.

Affect of thermal break material on peak load bolt tension

The tension in the bolts was monitored to gain insight into stress redistribution that occurs during loading of the connection. Bolt tension was recorded prior to loading and at the peak load during final load cycle. The average change in tension of the two bolts at the top of the connection (negative moment side) and bottom (positive moment side) is plotted in Figure 6. The data are grouped into subsets based on the peak applied load. As expected, greater tension is observed in the bolts on the positive moment side of the connection and this trend is clearest at the higher applied load. These results and consideration for the presence of the lower modulus material being compressed in the joint suggest the methods used to analyze and design traditional steel bolted connections are appropriate for FRR thermal break pads. The methods will be conservative when considering aspects such bearing area on the thermal break material if loads are large enough to induce lift off of the beam end plate.



a)



b)

Figure 6. Change is bolt tension between zero and peak load, a) 11,000 lb peak load, b) 7,000 lb peak load.

Conclusions

From the results of this experimental program the following conclusions were developed:

1. The use of thermal break materal will increase the beam deflections due to increased rotation at the connection.

2. The additional joint rotation in connections with thermal break material was approximately 10% of the base joint rotation for 1-inch plate and 20% for a 2-inch.
3. Design and analysis of connections with thermal break material should follow the approaches used for connections with fillers with appropriate accommodation for the properties of the thermal break material, including a check against crushing the plate material.

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Acknowledgements

The authors thank the research assistants involved in this study - Nicolette Camishion, Patrick Downey, Sean Marko, Graham Neville, Matthew Oostdyk and Thomas Panaro – for their time and efforts. Charles Linderman, Aaron Nolan, and Karl Dyer were instrumental in assisting with specimen and loading frame fabrication.