Construction and Building Materials 181 (2018) 510–526

Contents lists available at ScienceDirect

Construction and Building Materials

journal homepage: www.elsevier.com/locate/conbuildmat

Measuring the effective Young's modulus of structural silicone sealant in moment-resisting glazing joints

Adam D. Lee [a,b,*], Paul Shepherd [a], Mark C. Evernden [a], David Metcalfe [c]

[a] Department of Architecture and Civil Engineering, University of Bath, Claverton Down, Bath BA2 7AY, UK
[b] PTCC Facade Design, Telecom Plaza, 316 Senator Gil Puyat Ave., Makati City, Metro Manila 1200, Philippines
[c] Centre for Window and Cladding Technology (CWCT), The Studio, Entry Hill, Bath BA2 5LY, UK

HIGHLIGHTS

- Structural silicone sealants bond glass panes to glazing frames and curtain walls.
- These sealant joints can provide torsional bracing for structural members.
- An new method of analysis is proposed, and verified experimentally.
- The new model may result in more efficient use of metal in glazing systems.

ARTICLE INFO

Article history:
Received 29 January 2018
Received in revised form 25 May 2018
Accepted 6 June 2018
Available online 15 June 2018

Keywords:
Facade design
Structural silicone sealant
Structural glazing
Elastic modulus
Curtain wall
Mullion

ABSTRACT

Structural silicone sealants are synthetic rubber adhesives used in the construction industry to bond glass and other sheet infill materials to the frames of windows and curtain walls. In this paper, two different algebraic expressions are proposed to describe the way in which the rotational stiffness of the adhesive connection – resistance to moments acting about the axis of the joint – varies with the sealant's cross-sectional dimensions and elastic modulus. Laboratory testing of DC-983, a two-component structural silicone sealant used widely in factory prefabricated glazing applications, has, with some caveats, validated the mathematical models.

1. Introduction

In the middle of last century there began to emerge, hand in hand with the glass box architectural style, a new method of constructing tall buildings. First, a frame made up of columns and beams was erected, to support the floors; then, to keep out the weather, the freestanding structure was enclosed with a lightweight, metal framed, skin [1–3]. Since that time, designers of these exterior "curtain walls" have been using the same set of assumptions when modelling the forces that are transferred from the sheet material covering the facade, which is often glass, to the members in the supporting frame. These structural idealizations are illustrated in Fig. 1, in four cross-sections through extruded aluminium "mullion" profiles, which are those that span vertically from one floor to another.

The first of the mullions, Fig. 1-A, is a simple box section. Aluminium curtain wall profiles of this sort, which must be cut and assembled at the construction site, became popular in the 1960s [e.g. [2]] and, for some applications, are still in use today. Glass is retained at the face of the wall system using a mechanical clamp. Rubber gaskets permit relative movement, in the plane of the wall, between the glass and the metal frame. So, the glass does not prevent the aluminium members from moving laterally. Also, the mechanical clamp at the edge of the glass permits rotation, as shown in Fig. 1-A, so glass deflections do not cause the framing member to twist about its longitudinal axis.

Another means of securing glass to its frame is to use an adhesive. This approach, known as "structural glazing" and shown in Fig. 1-B, is relatively new. The first high-rise tower with a structurally glazed curtain wall was completed as recently as 1986

* Corresponding author at: PTCC Facade Design, Telecom Plaza, 316 Senator Gil Puyat Ave., Makati City, Metro Manila 1200, Philippines.

E-mail addresses: adamlee@torstencalvi.com (A.D. Lee), p.shepherd@bath.ac.uk (P. Shepherd), m.evernden@bath.ac.uk (M.C. Evernden), david.metcalfe@cwct.co.uk (D. Metcalfe).

https://doi.org/10.1016/j.conbuildmat.2018.06.038
0950-0618/

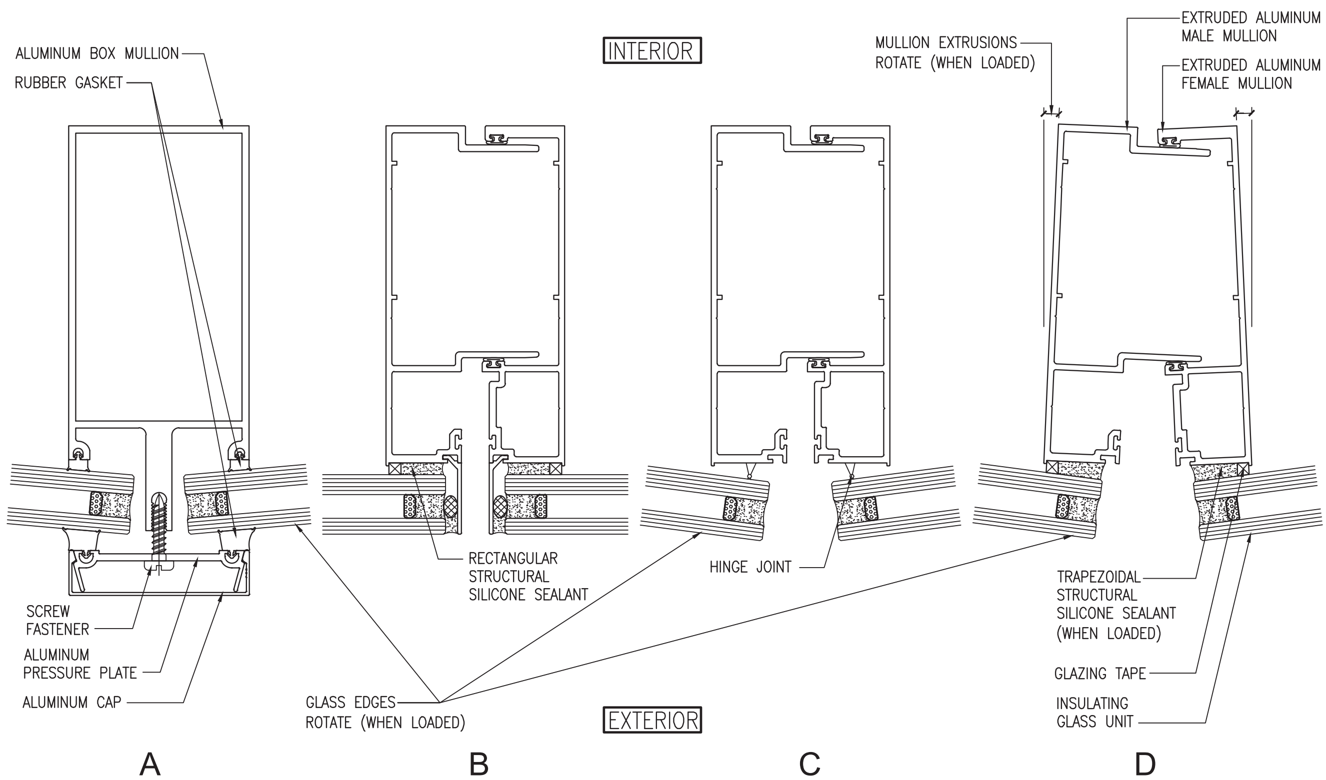

Fig. 1. Cross-sectional shapes of vertical mullions. In detail "A", glass is held mechanically to a simple box section. Structural sealant, in detail "B", bonds glass to the male and female profiles of a unitized wall's split mullion: this design's structural idealization is shown in "C", although "D" may be a better represent the wall's actual behaviour when subjected to wind load.

[[4] p. 53]. Since then, architects have embraced the new aesthetic, using the technology to create large, flat facades, without any metal components to the exterior of the glass. Structural glazing has become a common and conspicuous feature of large buildings around the world. Current structural design methods and usage guidelines for the adhesives – structural silicone sealants – are detailed in ASTM C1401 [5]. The reasons for inclusion of the "glazing tape" shown in Figs. 1-B and -D, and the effect that this tape has upon structural performance, are explained in Section 7.3.

Fig. 1-B shows the E-shaped male and female extrusions that together form the split mullion of a modern unitized curtain wall. In such designs, the facade is made up of discrete panels that can be prefabricated. Because of this, and other, practical advantages [[6] p. 4–5; [7] p. 86], the great majority of the world's new curtain wall is of this type [[8] p. 82]. From a structural standpoint however, the split mullion's narrow profiles are, in torsion, less rigid than the box sections they replace (Fig. 1-A). Consequently, it is frequently the case that prevention of buckling is the dominant concern for today's facade engineers.

Lateral torsional buckling (LTB) is the mode of structural failure caused and characterized by extreme axial rotation of a flexural member's cross section. At the onset of failure by LTB, a glazing system's profiles deflect in the manner shown in part D of Fig. 1. The analysis of LTB is complex [e.g. [9] Chapter 5], and is affected by parameters aside from bending moment distribution, material properties, cross-sectional shape and distance between supports. Other significant particulars are the member's initial straightness, and also the load eccentricities, which may themselves be functions of the profile's rotation.

If one of a member's flanges is restrained to prevent it from rotating about its long axis, then LTB can be prevented. The moments that are transferred to such braces can be estimated analytically [e.g. [9] Eq. 12.10], and the magnitude of the required torsional resistance is small. In a typical, unitized curtain wall system, the panes of glass or other sheet infill materials that are connected to the mullion's outer flanges have ample structural capacity to serve a torsional braces. However, current design guides advise that, even in structurally glazed systems, glass and infill materials should not be considered to be restraints [e.g. [10]]. Consequently, in structural analysis, mullions are modelled [as in [11] Part VIII, pp. 56–61] with the assumption that no moment is imparted to them by the glass. The structural idealization of the glass support is a hinge, as shown in Fig. 1-C.

In reality, because the structural sealant joint has stiffness, Fig. 1-D might better describe a unitized mullion's mid-span condition under wind load. In this diagram, positive wind pressure causes the glass to deflect toward the interior of the building and, as a consequence, moment is transferred through the structural silicone sealant to the mullion profiles, whose inner flanges move toward each other. The onset of LTB in the mullion profiles will, therefore, be affected by the moment resistance of the sealant joint.

Facade engineers are interested in improving current methods of predicting LTB [12,13] because, with continuing advances in the sizes of the panes that can be processed by glass fabricators, the structural members in exterior wall systems are becoming increasingly slender [10]. Research by others [e.g. [14]] suggests that a structural silicone joint may provide sufficient support to prevent LTB in some cases, but a recent survey [12] showed that facade design professionals have insufficient information to assess whether an attachment to a glazing system's frame will be effective as an LTB restraint. The analytical steps proposed in this present paper might therefore be incorporated in a more comprehensive model, to predict the angle through which a framing extrusion will rotate when full design load is applied, and thus demonstrate that the frame's resistance to LTB is adequate.