Key Engineering Materials
ISSN: 1662-9809, Vol. 710, pp 327-332
doi:10.4028/www.scientific.net/KEM.710.327

Submitted: 2016-05-23
Accepted: 2016-06-08

Aluminium Framing Members in Facades

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Keywords: Curtain wall systems, Aluminium, Mullions, Transoms.

Abstract. Curtain wall systems are considered as envelop of a building, generally made of a lightweight material such as aluminium. The curtain wall façade does not carry any weight from the building, rather it transfers loads that are incident upon it to the main building structure through connections with floors or columns. This paper addresses some key issues in satisfying the respective limit state design checks. Two mullion profiles 85mm and 125mm deep of three manufacturers are analysed showing that the different extrusions of mullion profiles does not have any drastic effect on its structural behavior. Due to the versatility and lightweight, aluminum has many advantages when used as a curtain wall framing material, but it has the distinct disadvantage of being three times more deformable than steel. Therefore, the fulfillment of serviceability limits is an important issue when designing the framing members, in order to avoid damage of connected glasses. Also, the importance of connections and steel insert are highlighted. Finally, some completed and in-progress ALUTEC projects with different curtain wall systems are presented. The paper is therefore interesting for the Façade Engineers involved in the design of curtain walls.

Introduction

Aluminum is extensively used in transportation, household applications and other industries. It is corrosion-resistant compared to iron, considering that aluminum oxide is not destructive but protective. The metal is impermeable and it does not affect the taste or smell of packed food. Industry uses aluminium quite often due to its extrudability and versatility. Profiles used for doors, windows, curtain walls, skylights, louvers, extruded brackets, perforated screens, flashing, trims, copings, claddings, sun screens gratings, handrails, building bridges, shutters, ladders, staircases, gutters, car parks, aircraft carriers, utensils, foil wrappings, bottle caps and cans, etc., all are made of aluminium. Aluminium's high strength-to-weight ratio and its ability to be extruded into any shape – no matter how complex, with tight tolerances make it an ideal material for design applications requiring maximum versatility from a cross-sectional area.

Concisely, curtain wall hangs from a structure like curtains hang in a home. These are considered as the building envelop commonly made of lightweight material such as aluminium, therefore easily handled and installed. When glass is used as glazing material, the great advantage of natural light penetrating deeper within the building is achieved. The curtain wall façade takes its own weight in addition to the external loads acting on it. These loads are then transferred to the main structure. The wall transfers wind loads that are incident upon it to the main building structure through connections with floors or columns. A curtain wall is designed to resist air and water infiltration, sway induced by wind and seismic forces acting on the building together with its self-weight. In the early 20th century, with the development of large glass panels, buildings were constructed with exterior load bearing walls, thereby supporting the load of the entire structure. Such a construction typology became more common from the 1930's when aluminium was made available as a construction material for the first time. In the mid of 20th century glass curtain wall started to be used as non-load bearing structure due to the development and widespread use of steel and later reinforced concrete. The exterior walls could be non-load bearing and thus much lighter and more open than the masonry load bearing walls of the past. At the end of the century, such walls tended to be unique and custom-made, fabricated individually from the cast iron, rolled steel and plate glass that just began to appear as industrialized production. This gave way to increase use of glass as an exterior façade and, therefore, the modern day curtain wall was born [1, 2]. The versatility of aluminium metal is complemented by the flexibility of the extrusion process. Other metals can be extruded but only few of those with the ease like aluminium and its alloys.

Curtain Walls systems

The stick system is the most common type of curtain wall used in the façade industry. It is installed as separate components at the project site after being machined in the factory. In Alutec, the systems commonly used are Technal, SAPA, EFP, Balexco; they are used for international airports, high rise apartments, office blocks shopping malls and institutional buildings, etc.
Some aluminium curtain wall manufacturer are for examples, (i) Technal, (ii) RC SAPA, (iii) EFP, (iv) Reynaers, (v) Wicona, (vi) Schüco, etc. Among the three systems for Mullion depth 85mm and 125mm, EFP system is slightly heavier, whereas SAPA profiles have slightly larger inertia. Since serviceability limit state for the curtain walling to resist wind loading is always a governing design perimeter as most of the time, depth of the profiles are restricted. Curtain wall systems made of steel instead of aluminium give the advantages of larger free spans due to its 3 times greater Young's modulus, narrower sight lines and improved thermal performance. Therefore, steel material gives optimum design with restricted depth of the mullion profiles. The high elasticity of steel guarantees a solid yet light and slender structure.
Some well-known manufacturers for steel mullions and transoms are, for examples, (i) Secco, (ii) Wright style, (iii) Forster, (iv) TGP, etc. Using steel curtain walls, the "frame width" can be narrow, i.e., the width of the profile can be reduced and this can be an advantage under the architectonic and aesthetic points of view. Regarding "frame depth", shallow depth mullion can be used in steel curtain wall system vs. a required depth for a typical aluminum curtain wall system. With steel curtain walling, "large spans" can be accommodated with neither additional reinforcement nor intermediate connections required. They can withstand considerably larger glass sizes than aluminium curtain walling. Lastly, about "durability", strength of steel profiles ensure long-term resistance to denting, scratching or deterioration. Steel built curtain wall systems can also include stainless steel cover caps for aesthetics or increased durability.

Design Criteria

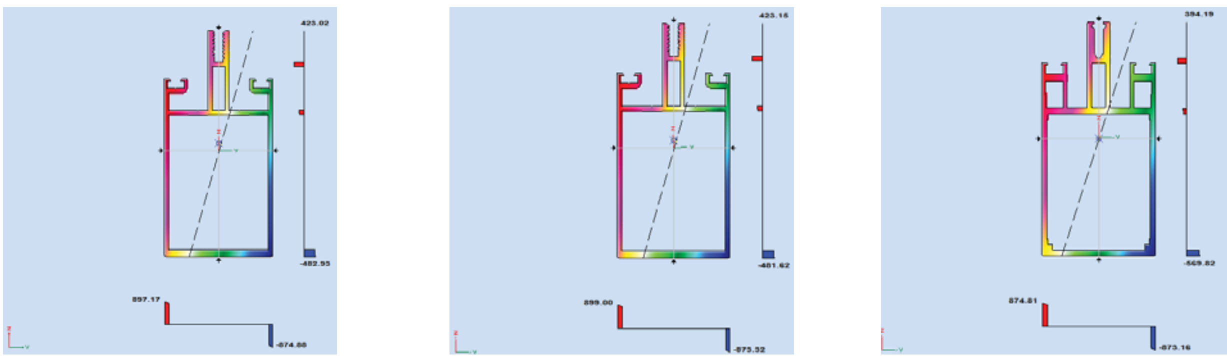
Deflection

One of the disadvantages of using aluminum for mullions is that the modulus of elasticity is about one-third the steel one. As a consequence, the deflections of aluminum mullions are three times greater than those of steel having the same cross sections and under the same load. Building specifications set deflection limits for perpendicular (wind-induced) and in-plane (dead load-induced) deflections. It is important to notice that these deflection limits are not imposed due to strength capacities of the mullions. Rather, they are designed to limit deflection of the glass, which may break under excessive deflection, as well as to ensure that the glass does not come out of its pocket in the mullion. Deflection limits are also necessary to control movement at the interior of the curtain wall. Building construction may be such that there is a wall located close to the mullion and excessive deflection can cause the mullion to contact the wall and produce damage. Also, if deflection of a wall is quite noticeable, public perception may raise undue concern that the wall is not strong enough.

Deflection limits are typically expressed as the distance between anchor points divided by a constant number. A deflection limit of span/175 or 19 mm is common in curtain wall specifications, based on experience with deflection limits that are unlikely to cause damage to the glass held by the mullion. Nevertheless, a deflection restriction for transoms when carrying the glass in plane is span/500 or 3 mm and it is generally considered by the codes. However, some panels require stricter movement restrictions, or certainly those that prohibit a torque-like motion. Deflection in mullions is controlled by different shapes and depths of curtain wall members. The depth of a given curtain wall system is usually controlled by the second moment of area required to keep deflection limits under the specification. Another way to limit deflections in a given section is to insert steel or aluminium reinforcement in the form of standard tube/plate/channel etc., to the tube of the mullion.

Strength

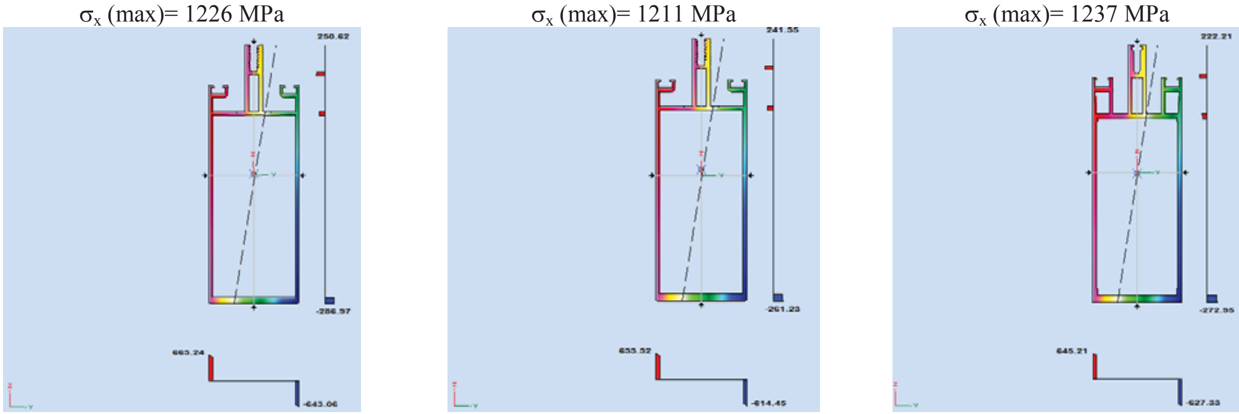
The maximum allowable stress of a particular material is generally not correlated to its stiffness, which governs deflection; therefore, in curtain wall design and analysis it represents a separate criterion. This often affects the selection of materials and the size of elements when approaching the design of the system. For instance, a particular shape in aluminum will deflect almost three times more than the same shape made of steel for an equivalent load, though its strength (i.e. the maximum sustainable load) may be equivalent or even slightly higher, depending on the grade of aluminum. Because aluminum is often the material of choice, given its lower unit weight and better weathering capability as compared to steel, deflection is usually the governing criteria in curtain wall design. In order to analyze mullion profiles extruded by different manufacturers, some internal forces (F_x =10 kN, M_y =10 kNm & M_z = 10kNm) have been applied to six cross-sections taken into account as representative profiles. Normal stress diagrams have been obtained as shown in Figure 1.



(a) NAPCO 85, σ_x (min) = 1359 MPa, σ_x (max)= 1226 MPa

(b) SAPA 85, σ_x (min) = 1341 MPa, σ_x (max)= 1211 MPa

(c) EFP 85, σ_x (min) = 1432 MPa, σ_x (max)= 1237 MPa



(d) NAPCO 125, σ_x (min) = 923 MPa, σ_x (max)= 861 MPa

(e) SAPA 125, σ_x (min) = 880 MPa, σ_x (max)= 834 MPa

(f) EFP 125, σ_x (min) = 909 MPa, σ_x (max)= 845 MPa

Figure 1. Normal stress contours of (a) NAPCO 85, (b) SAPA 85, (c) EFP 85, (d) NAPCO 125, (e) SAPA 125, (f) EFP 125

Each stress value displays with a coordinate for which the extreme stress value was calculated. The neutral axis is displayed as a dashed line in the cross-section. Comparison of the different type of stresses (as defined below) normalized to values of weight of profiles have been also made (Fig. 2).

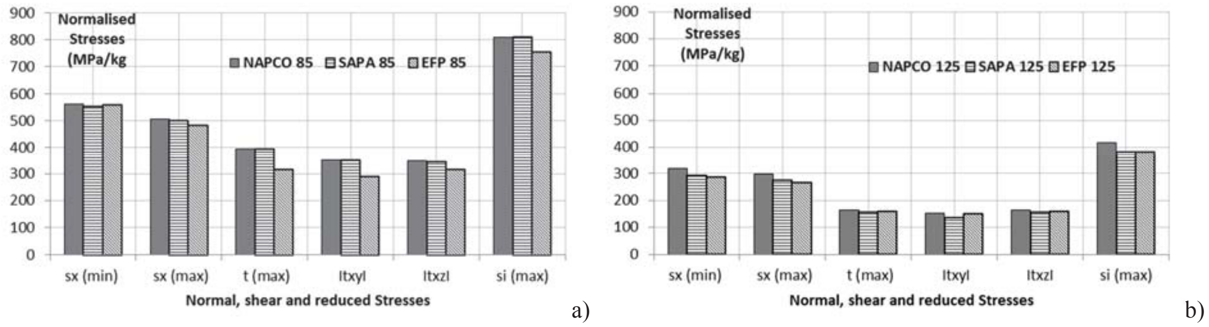


Figure 2. Comparison of stresses normalised to the profile weight for (a) 85 mm and (b) 125 mm deep mullions

Where sx denotes normal stress (maximal and minimal), |txy|, t(max) and |txz| are the shear stresses, Stress si denotes values of reduced stresses calculated according to a selected hypothesis (Huber–Mises–Hencky, Tresca). It can be observed that the profile extrusion does not have a huge influence in structural terms both for serviceability limit state (as inertias are quite close each to other) and for ultimate limit state (as the stresses are approximately the same).

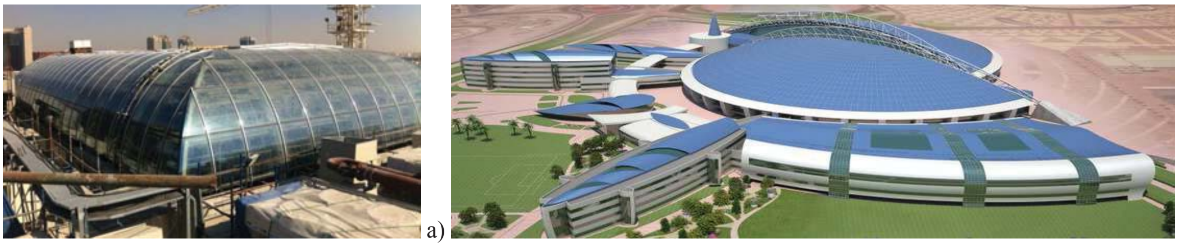
Connections

The horizontal elements are generally connected to the vertical ones through an extruded channel called connector. Every manufacturer extrudes its own connector. Some connectors have the possibility of transferring moments to the verticals whereas some other transfer only shear forces. As a general rule, these are considered to transfer shear as the modeling assumptions are simple and more conservative from structural point of view. The vertical members are then connected to the beams/floors through the use of wall mounted or shoe brackets depending on the height of an intermediate supports of the curtain wall. Again, very interestingly, these brackets, wall mounted having fin plates or shoe brackets can be extruded. Many times, these extruded brackets are made of steel. The framing members need to breathe during high or low temperature if not designed for thermal loading. In this case, slotted holes are generally provided, the slot being limited to the structural calculations. Continuous curtain walls (multiple spans) and single span fixed curtain walls (moment connections) are more susceptible to strength checks at the connections while generally the deflections are within limits. Problem arises when the curtain wall is single span with pin connections at the ends, where mostly serviceability limit state governs the structural design. Some designer prefers to use a kicker bracket just below the top connections where the false ceiling exists, but the issue becomes more important when there is restriction of providing any kicker bracket. In that case, steel inserts are generally provided by the designer to satisfy the limit states within the restricted depth and narrow widths of the curtain wall systems. Edge distances, strength of concrete, anchor type, anchors spacing are other important parameters that need attention while designing the anchorages. Ignoring one of these factors while dealing with curtain wall anchorages may yield to a big disaster due to the brittle failure of glass.

Case Studies

In this section, some important completed and in progress ALUTEC projects using different curtain wall systems are briefly presented, with the aim of illustrating the main characteristics of the adopted system and the corresponding potentialities. In particular, the following projects are taken into consideration:

- Qatar academy Al Khor, composed of stick curtain walls where Technal system of 180mm deep mullion with and without reinforcement has been adopted. The project also foresees huge canopies, balustrades, louvers, doors and windows.
- Le Boulevard project, consisting of doors, windows, curtain walls, skylight (see Fig. 3a), lift enclosures, balustrades, etc., where the RC SAPA system has been adopted [9].



a) b)
Figure 3. Curtain wall of the Le boulevard skylight (a) and Aspire Academy exterior work (b)

- Al Ahli sports club, one of the finished projects composed of curtain walls, free standing glass balustrades and composite claddings. About 500 trusses around 6 m cantilevered from a space frame have been installed. These were covered with aluminium composite claddings. In this case the Technal system using 140mm deep mullion profiles were applied.
- Extension of Aspire Academy (Fig. 3b) with curtain walls, glass balustrades, staircase handrails, where the Technal system with custom fabricated curved mullions have been used. In FPC building the adopted mullions are curved; therefore they are fabricated from aluminium sheets. Technal curtain wall systems for straight and inclined portions (FPC and boarding) are adopted, whereas for the curved part customized mullions are employed (FPC). For FPC customized mullions 240mm deep with pitch of about 3 m are utilized.
- Health Centers, Nuaim, AL Muntazah, Al Wajba & Mauthier, consists of curtain walls, Mashrabiya, skylights, internal glass partitions and balustrades. The EFP and Technal system are employed. The profiles were generally 177mm and 55mm deep with and without steel inserts. The spacing of the curtain wall varied from 1.1m to 1.85m. Maximum overall height is 11m with two intermediate supports.
- HMC simulation center with curtain walls, vertical and horizontal sun control trellies, glass fins, decorative glass bridge and balustrades. In this case the Technal System with 140mm deep mullions is used with and without steel insert.
- Mashreb Doha land, consisting of fire rated glass floorings and bronze coated decorative screen. For the glass flooring Technical Glass Product system is adopted.
- National Cyber Security, with curtain walls and skylights, realized with the Technal system. Since the height of the mullions without any support is 11 m, therefore Transoms are considered to be the main carrying member for wind load and they are reinforced with steel insert.
- NPP0064 is an ongoing project consisting of three different buildings, namely, the Mwani building (Fig. 4a), the twisted control tower (Fig. 4b) and the custom building (Fig. 4c). These buildings are composed of unitized and stick curtain wall system. Around 200 unitized panels on Mwani building and around 1200 panels for control tower have been installed. A mock up of 12 unitized panels (see Fig. 5) has been recently installed for inspection purpose. These are bounded by structural silicon with gasket behind.

a) b) c)
Figure 4. On-going NPP0064 project: (a) Mwani building, (b) Control tower, (c) Custom building

a) b)

Figure 5. Mock up of 12 panels (a) and production of unitized panels (b) for the NPP 0064 Mwani building

Concluding remarks

The current paper briefly addressed some issues and highlights on curtain wall systems. It is believed that proper adoption of mullions will give a good performance of the curtain walls system in term of structural stability, aesthetical view, drainage requirement, thermal requirement and, above all, cost effectiveness. Steel insert and proper anchorages of curtain walls are useful for controlling the deflection of the overall curtain wall systems. Adoptability of aluminium and steel curtain wall being stick or unitized system depends on the design of architects and structural engineers to fulfill the desired requirements of client. An adequate anchorage (rigid or pinned) of the curtain wall is the key for its structural performance to resist lateral forces. Optimum and sage design solutions are always hidden within the adopted system and, therefore, needs to be explored.

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