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Consideration Factors of Glazing for Supertall Building

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Biography

Jinyoung Jung has been employed by Dow Corning for over 14 years. His role is senior technical professional based in Korea. Jinyoung Jung focuses on the Construction Industry where over the years he has made significant contributions in both product and application development. Based on a strong chemistry background he has contributed to developing and applying multiple new silicone technologies for the industry including:

- Non staining silicone sealant for curtain-wall façade
- Silicone window perimeter sealant for apartment
- Fast cure silicone insulating glass 2nd sealant
- Innovative silicone hot-melt sealant for window assembly
- High performance structural silicone sealant
- Silicone construction gasket for structural glazing
- Sanitary grade silicone sealant
- Water repellent treatment for concrete, brick & building material.

Jinyoung Jung's influence and expertise extends beyond Korea. Many customers throughout Asia and abroad have benefited from the passion he has for construction applications. Some of his broader industry contributions for include improvements to productivity & durability of building components as well as improved aesthetics of curtain wall façades.

He has shared his experiences and knowledge on silicone material and its innovative applications with various levels of the construction value chain including general contractors, architects, consultants, fabricators, glaziers, material suppliers and research institutes.

Currently he holds several memberships for research programs with government affiliation and Cooperative Organization for Standard Development. He is actively working with the organizations for developing energy efficient building façade and setting up national specification on structural sealant material & structural glazing.

Abstract

Taken as a case example, the Burj Kalhifa is an example of using high quality glazing in a supertall building to improve the satisfaction of the tenants through prevention of air and water leakage, façade integrity and energy efficiency.

Many factors need to be considered when glazing super tall structures. Environmental factors such as high temperatures, ultra-violet radiation, inclement weather/high wind loads and even seismic activity all need to be considered when specifying products to ensure high quality glazing. The considerations for material selection for glazing and long term adhesion durability on specific substrates need to be taken for the safety and lower maintenance of building façade. Special consideration for aesthetic performance of the façade is also important to have lower maintenance cost through building life cycle. Finally, excellent quality control/quality assurance is critical throughout the entire construction process.

Following 50 years of prosperity since the Korean War, several supertall buildings are planned for Korea. However, Korea currently does not have guidelines or specifications specific to glazing systems and the materials used. The author presents relevant global structural glazing and insulating glass industry guidelines and specifications, with specific focus on issues related to Quality Control, for consideration of use on Korean projects. The author also presents data on physical properties and field performance of several different silicone sealants.

Keywords: Structural Silicone Glazing, Curtainwall, Weatherproofing, Durability, Adhesion

Introduction

The world's tallest building, Burj Khalifa skyscraper, stands 828 m above ground level. The tower's design is derived from patterning systems embodied in Islamic architecture, this iconic project is set to break many records whilst overcoming the greatest of challenges and technical difficulties, not least of which are the wind forces dominating the structural design of the tower, the logistics of moving men and materials at extreme heights and construction of the building envelope. It is clad in an aluminum and glass facade which totals 132,190 square meters of which 10,300 square meters are high performance glass. Advanced glass technology was used to resist heat transmission from the sun and save energy. And high performance silicone material was used in order to manage the internal pressure foreseen within the insulating glass units due to the high altitude and to bring additional security to the insulating glass units which were mechanically fixed to the superstructure.

As seen in the example, modern architecture is one of best examples for hybrid of science and technology. None of high rise buildings could be built without serious economical and technological considerations. If we divide tall building simply it can be core and shell. Both have independent and vital roles but should be harmonized as one body at the same time. Most architects would like to have very much of freedom for building skin, especially designing building façade with curtain wall system is one of most challengeable part for a architect because there must be economical and technological limitations.

In such a modern architectural design, sealants play a crucial role in manufacturing the weather tightness and the thermal insulating of claddings and engineering structures. In commercial applications such as Structural Silicone Glazing, and Insulating Glazing, the sealant also provides the structural adhesion between the frame and glasses.

Silicone Structural Glazing (SSG) is a method utilizing a silicone adhesive to attach glass, metal, or other panel material to the structure of a building. Windload and other impact loads on the façade are transferred from the glass or panel through the structural silicone sealant to the systems' framework. Silicone Structural Glazing systems are currently a very common method of glazing throughout the world. SSG's use has become extremely popular, and its principal advantages include the freedom SSG presents to architects by providing infinitely more façade design options as glass and panels no longer must be secured to the façade with mechanical methods, and it offers economical benefits to the contractors and fabricators by increasing productivity in assembly and installation. For these reasons and performance benefits that SSG provides to the overall glazing system including

waterproofing, acoustic, and thermal benefits to the system, most landmark projects in the world utilize this attractive glazing technology.

With regards to the concerns for sustainable architecture in recent days, the designer and the fabricators have very keen interests how their next generation of architecture can contribute for the society sustainably. There must be many kinds of aspect influencing the sustainability of building through total life cycle. Not only designing the building utilizing many of advanced technologies for renewable energy or for high energy efficiency but also operating the building with optimized cost are important to have truly sustainable architecture. So, designing and fabricating the skin of supertall building with deep considerations for lowering operational embodied energy are also important to have the sustainably because the building skin is most susceptible to lose energy via air and water leaking, thermal bridges and broken of insulation.

Durability

Designing building skin by silicone structural glazing gives many of benefits as mentioned above but there are key things need to be considered before and during fabrication in order to enjoy performance benefits. First of all, how to specify sealant for durability? What criteria should be a sealant specifier use in the selection of a sealant product in order to have confidence in its performance and durability in its end use.

There may be some parameters:

- Mechanical performance criteria such as elasticity, modulus and movement capability
- Adhesion to specific substrates

Seeing the durability of the glazing, it's not the independent matter from the safety of building façade. Not only cladding material (normally glasses) itself also for the glazing need to be considered for its proper use upon the guidelines by relevant industry norms. Safety of SSG mostly would mean proper structural joint designing before installation and durability after installation of structural glazing system. The specifiers could get very useful information for material specification of structural sealant, test method for mechanical performance and proper application guidelines from some industry standards. There are several generally accepted industry specifications for structural sealant and glazing. In US, there are ASTM C 1184 Standard Specification for Structural Silicone Sealants defines minimum tensile strength after harsh conditioning and accelerated weathering and ASTM C 1401 Standard Guide for Structural Sealant Glazing defines structural sealant design considerations. In Europe, there is ETAG 002 Guideline for European Technical Approval for Structural Sealant Glazing Systems. It includes both for structural sealant specification and proper structural sealant designing.

The primary requirements for those industry standards are focused on durability, specifically against weathering elements (UV, rain, temperature, various pollutants). The resistance to weathering is generally assessed by verifying that the products do not fail cohesively and adhesively, due to hydrolytic or UV induced bond breakage that can occur within the bulk of the product or at the interface between the product and the substrates, during its expected life time. [1] Meeting those industry specifications can be basic fundamental for the specifier to select right sealing materials.

Although structural silicone glazing has been utilized for approximately thirty years in Korea, the understanding of its technology was low and limited. Consequently, Korean projects experienced many quality issues during assembly and construction, even in very recently finished buildings. Adhesion loss and water infiltration occurred on more than one project, and the time and cost to repair these issues were substantial. More importantly, assessing responsibility for such failures by each participant in the construction process is highly arduous. The causes of such failures are difficult to pinpoint, but one of the culprits would be the lack of availability of an "industry guide" for structural sealant and its application. It is very urgent matter for Korea construction industry to have national specification for sealant and guidelines of structural glazing for Korea. There are some backgrounds for the necessity,

- Not clear material specification of sealant for commercial purpose and re

sidential purpose
- Lack of safety of the glazing for the workers
- No blockage for the material which could not meet long term durability e xpectation
- Faulty structural silicone designing
- Ambiguity for role and responsibility when there is a quality issue
- Very much for price oriented market not quality oriented

In 2010, International Organization for Standard set up new guidelines for Structural silicone specification and application guidelines for the glazing works. So, the authors of this paper would like to better inform the domestic market about the actual performances of SSG products locally available based on the evaluation following the international industry norm ISO 28278, Glass in Building – Glass Products for Structural Sealant Glazing – Part1: Supported and Unsupported Monolithic and Multiple Glazing.

The requirements from the guideline are for tensile testing in a standard condition over 0.5 MPa as a minimum for the stress and more than 90% cohesive failure mode. Additionally tensile value at harsh conditions should be measured, and its delta mean value as a ratio to the initial value shall be over 75%.

Table 1. Tensile Strength of Structural Silicone Sealants available in Korea

Sample Type	Maximum Point Stress (MPa)			ΔX_mean %	ΔX_mean %
	X mean(23C)	X mean(-20C)	X mean(80C)	(-20C)	(80C)
1	0.972	1.202	0.91	124%	94%
2	0.849	1.02	0.707	120%	83%
3	0.97	0.921	0.783	95%	81%
4	0.704	0.731	0.24	104%	34%
5	0.861	0.814	0.549	95%	64%
6	0.838	0.995	0.661	119%	79%
7	0.925	0.772	0.172	83%	19%
8	1.224	1.238	0.985	101%	80%
9	0.508	0.569	0.49	112%	96%
10	0.85	0.992	0.747	117%	88%
11	1.061	1.112	0.856	105%	81%
12	0.954	0.979	0.763	103%	80%
13	1.017	0.936	0.888	92%	87%
14	1.315	1.288	0.91	98%	69%

Various silicone products for structural glazing and structural insulating glazing used in Korea were evaluated following ISO 28178 Part 1 requirements. Some of them could not meet the specification. Which means not all the silicone products are enough durable to meet minimum requirement so the specifier of building façade should select right material for intrinsic performance of buildings.

Consecutively accelerated weathering was conducted for long term performance of silicone glazing sealant. And some products showed adhesive failure onto common glass surface and anodized aluminum surface. Weathering through artificial light and water exposure is effective way to predict sealant durability for mechanical strength as well as adhesion durability on the substrates. The products had adhesive failures also showed poor mechanical strength after accelerated weathering.

Table 2. Tensile Strength and cohesion/adhesion properties of structural silicone after exposure to artificial light through glass and to water

Sample Type	Before weathering	5000 hrs Xenon weathering	Failure mode
	(MPa)	(MPa)	
1	0.972	1.08	Cohesive Failure

2	0.849	0.786	Cohesive Failure
3	0.97	0.773	Cohesive Failure
4	0.704	0.469	Adhesive Failure
5	0.861	0.67	Adhesive Failure
6	0.838	0.845	Cohesive Failure
7	0.925	0.391	Adhesive Failure
8	1.224	1.156	Cohesive Failure
9	0.508	0.436	Adhesive Failure
10	0.85	0.82	Cohesive Failure
11	1.061	1.11	Cohesive Failure
12	0.954	1.042	Cohesive Failure
13	1.017	1.123	Cohesive Failure
14	1.315	1.139	Cohesive Failure

Sealants have been developed to seal joints between numerous substrates, the more common of which are masonry, concrete, metal, and glass. These are generally classified as porous or non-porous. Some substrates are more difficult to adhere sealant to than others. Surface characteristics vary considerably, and some may not be suitable for achieving a joint seal unless treated either mechanically or chemically, or both. So, the adhesion on the substrates requires special consideration and consultation with both the substrate and sealant manufacturers to determine suitable joint preparation methods and which primers should be used before joint materials are applied.

The substrates must be properly prepared in all cases. They must be clean, dry, sound, and free of loose particles, contaminates, foreign matter, water-soluble material and frost or ice. Also, many sealants require primers on all substrates, while some require them on only certain substrates or on none at all. The need for a primer and the adhesion results achieved can vary, not only with the substrate, but with the quality of substrate. No consistent recommendation can be made regarding which substrate surfaces will require priming. Priming is dependent on the sealant manufacturer, sealant type, substrate, and, some instances, use. [2]

Normally the functions of primer are to change the chemical characteristics of the substrate surface to render it more suitable for the sealant, to stabilize the substrate surface by filling pores and strengthening weak areas, and to block capillary pressure of moisture through the substrate surface. But still sealant manufacturer should be consulted if unexpected conditions exist or are suspected. In general, field tests should be performed to determine the proper treatment and sealant or primer selection, or both.

Weatherproofing

Because sealing the joint with sealant material is economical and practical ways of doing for weather tightness, if it’s properly installed there could be no comparable weatherproofing replacement. But most people do not think about its importance seriously. For high rise building construction, it’s not easy to check every part of sealing process for the façade so there might be serious weatherproofing issues which can’t be addressed properly unless there are special considerations for joint design and material selection.

Although there is no strict accelerated weathering requirements are included, there are commonly used industry guidelines for weatherseal such as ASTM C 920 Standard Specification for Elastomeric Joint Sealants and ISO 11600 Building Construction – Jointing Products – Classification and Requirements for Sealant. For Korea, there is a national standard for classification of construction sealants which is KS F 4910, Sealant for sealing and glazing in buildings.

For ISO 11600, there is a practical way of evaluating performance of weatherproofing joint sealant that is elastic recovery. Elastic recovery is the property of sealant whereby initial shape and dimension of material are wholly or partially restored on removal of the forces causing deformation. This property has important meaning for the weatherproofing joint which will have thousand times of expansion and contraction due to thermal dilations of building joints. When some of locally available weather sealants were evaluated for elastic recovery under ISO 11600, only one product passed minimum requirement.

There are so many weatherproofing sealants available from the market and all they are claimed for high performance of weather tightness. But real performances of each product are different, the specifier should select the material which has proven case histories and well managed by quality system. Consultation for joint dimensioning from the supplier will make the joint more weather tight.

Table 2. Elastic Recovery of Silicone Weatherseal in Korea

Sample	S-1	S-2	S-3	S-4	ISO 11600 Requirement
L0 (mm)	12	12	12	12	-
L1 (mm)	24	24	24	24	-
L2 (mm)	18	19	18	14	-
RE (%)	51	41	48	82	60 <

$$RE = \frac{(L1-L2)}{(L1-L0)} \times 100 \quad (1)$$

Where, RE is elastic recovery %, L0 is initial width of joint, L1 is width of joint at the time of extension, L2 is width of joint at the time of recovery. S-1, S-2, S-3, S-4 are sealant kinds.

Aesthetic

Aesthetic satisfaction for building maintenance is getting more important than before to lower maintenance cost through building life cycle. Many efforts have been dedicated by industry during the last years to better understand the aesthetics effects of sealant in buildings, in particular those that affect the sealant itself and those that affects the adjacent building substrates. Aesthetic issues are typically dirt pick up, microbial growth, chalking, sealant reversion, fluid migration, surface crazing and change of color. All of these can affect the long term performance of the sealant. [1]

There could be severe dirty appearance on the building façade because of migrants from weather sealant. All the material for building cladding could be influenced by the pollutants from the environments and the potential contaminant from the sealing material The phenomenon could be simple dirt pick up or fluid migration on the joint and the panel system. But there is an alternative product which has lower migrants in the formulation using proprietary technologies from certain sealant supplier. This option will give lower building maintenance cost as long term besides on weatherproofing performance. Picture 1 is the real outdoor exposure mock up for 3 years with several weather proofing sealants from different sealant suppliers. Left side of picture showed severe staining due to polymer migration from the sealant but the right looked much more reasonable.

Picture 1. Different degree of staining by each weatherproofing sealants on the panel

Quality Control

Along with selecting right glazing material under relevant industry specification and guidelines, proper quality control procedures and application expertise should be ensured to have originally intended performance of building façade and design of building skin. A large percentage of cladding seal defects and failures can be attributed to poor workmanship, the lack of proper site supervision and poor fabrication.

In order to minimize failed cladding works there must be proper fabrication check for every stage of the fabrications for clean, accurate and consistent application. More specifically all the required steps such as what needs to be done, where it needs to be done, when, who is to do should be well documented and passed over to related personnel. Finally if proper supervision on the job site and appropriate communication with workmanship are conducted, there will much less quality issues on water leaking, air infiltration and consequently less energy losses [4].

Once silicone sealant and adhesive are cured properly, it will form durable and flexible anchor for curtain wall system. Long term durability of its structural function has been proved based on many of successfully fabricated land-mark projects over the world for last 40 years. But the architects and fabricators should remember that silicone materials still require proper applications and environmental conditions during the fabrication of façade system to have enough mechanical strength to retain heavy weight of panels. Right performance of structural glazing system will be heavily dependent on appropriate chemical reactions from an inside of applied structural silicone and the interface between adhesive material and specific substrates. This is why every silicone suppliers recommend that having quality processes at the job site for checking cure status of structural silicone and laboratory adhesion confirmation from silicone suppliers before mock up.

Checking Snap Time for two part structural silicone and surface cure check for one part structural silicone before daily fabrication are most simple and effective way to ensure its chemically curing state of applied adhesive material. Depending on suppliers, there is recommended mixing ratio for two part silicone, generally it's 8:1 ~10:1 by volume. Properly mixed two part structural silicone will have 30 ~ 60 min snap time. For 1part structural sealant, it will have un-tacky smooth surface within in hours after apply. As pointed out earlier, all the results for curing status must be documented properly on quality control log under right supervision.

Picture 2. Measuring required structural bite dimension upon deglazing for curtainwall units

Picture 2 is for deglazing of curtainwall unit. It is one of powerful quality control procedures to check

the status of applied structural sealant for curing, joint filling, adhesion and required structural sealant dimensions. Agreed frequencies and scope of the works between quality control parties must be clearly addressed and carried out as regular basis for the documentation.

Table 3. Example Quality Control Log for Degalzing of Curtainwall Unit

	Project Name:		**Date:**		**Applicator:**		
	Frame ID	Panel Size	Product	Lot number	Application date	Structural Bite	Glueline
1							
2							
3							

Table 3 is the example for the documentation of deglazing. It could be modified upon the tastes of curtainwall fabricators and contractors. If it's conducted regularly and well documented, it gives piece of mind for the fabricators, building designer and the building owner. Recorded documentation for quality control will be only evidence to prove taken procedure for the fabrication and powerful hints if there are any quality problems.

Conclusion

Supertall building has several important meanings for the society by cultural, environmental, tourism and economical. Probably environmental contribution of supertall buildings by reduced embodied energy for construction and maintenance have more weight than before for modern architecture to face continuous concerns on global greenhouse gas issue. Particularly the façade of supertall building made of popular building cladding system so called curtain wall expected to have more challenges due to design difficulties and technological limitations but that's the inevitable hurdle or even a mission for a architect toward the society to give those important contributions.

Sealant and adhesive take small portion for total budget and mass volume of building construction but it has own contribution factors. For example, structural silicone sealant is one of key contributors for the architects to fulfill unique building design based on it's flexible structural features. It allows an architect to contribute for the society cultural aspect, economical aspect and so forth. Once wall cladding successfully done using structural silicone and weatherproofing sealant, it will give huge tangible benefits for all people in the society but if it's fails, it could make human made disaster.

Better energy saving through building façade and increased comfort for the tenant preventing thermal losses can be achieved not only using high performance insulating material also using durable sealant material. Like crucial other building material such as insulating glasses, metal panel system for building faced, sealant also has unique role to lower maintenance cost for whole life cycle of the building. Water leaking and air infiltration are one of major concerns to have lower life cycle cost global trend. Selecting right sealing material which has proven durability together with proper application can contribute to achieve those targets.

Whatever aspect they are for sealants in building construction, either for structural function or weatherproofing function, it's the matter of durability and proper quality control. How these could be achieved? First thing to do is probably checking and following relevant industry specification and guideline.

Several super-tall buildings are coming to Korea, some are under detailed planning for its designing and erection. Also as seen the results through the evaluations for locally available structural silicone and weatherproofing sealants, some of them are not enough durable to maintain original building design performance. This gives right backgrounds for Korea Construction Industry to set up for their national guidelines soon.

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