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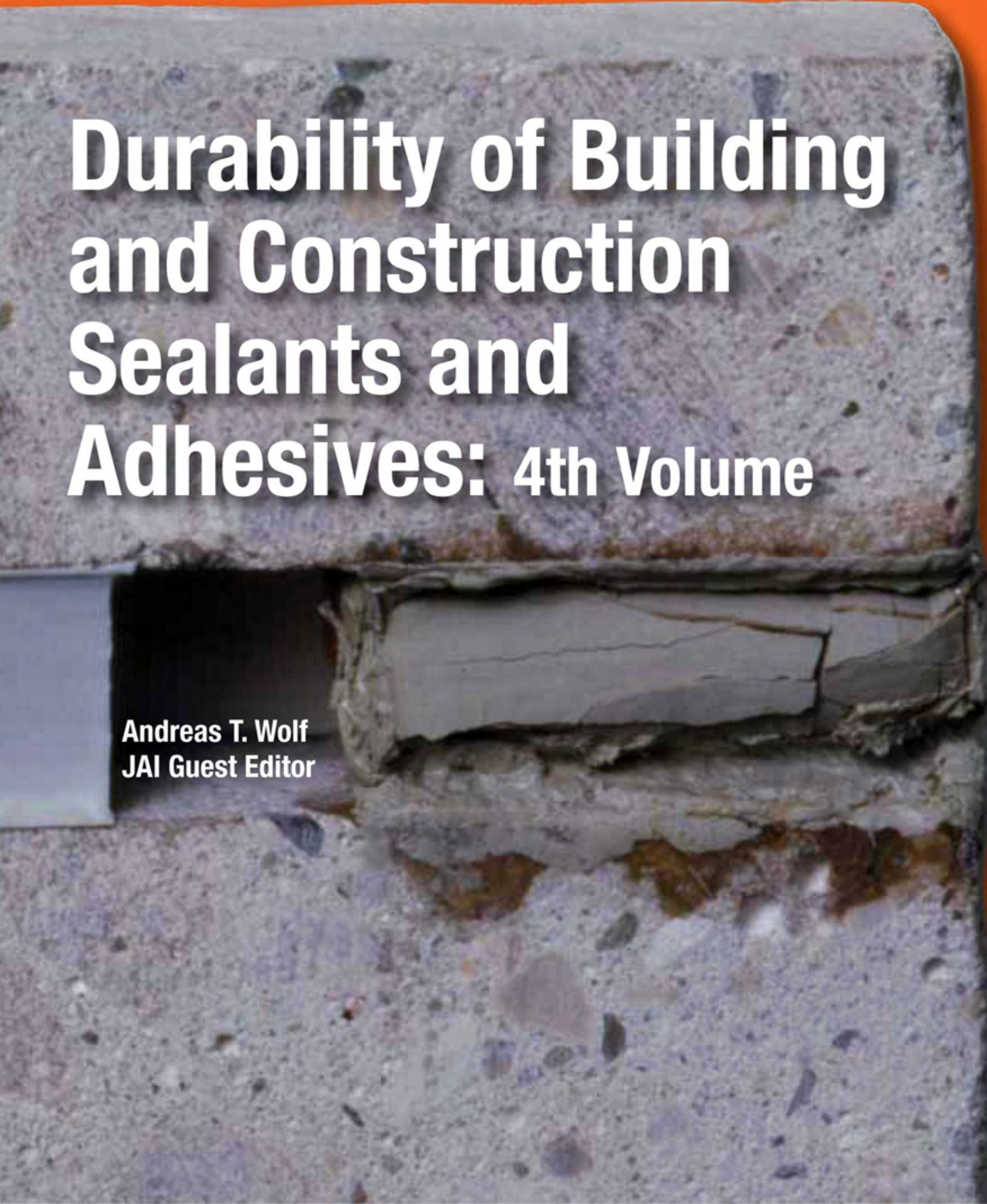
Durability of Building and Construction Sealants and Adhesives: 4th Volume

Andreas T. Wolf
JAI Guest Editor



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Foreword

THIS COMPILATION OF *THE JOURNAL OF ASTM INTERNATIONAL (JAI)*, STP1545, on *Durability of Building and Construction Sealants and Adhesives: 4th Volume*, contains 25 papers presented at the symposium with the same name held in Anaheim, CA, June 16–17, 2011. The symposium was sponsored by the ASTM International Committee C24 on Building Seals and Sealants in cooperation with the International Union of Laboratories and Experts in Construction Materials, Systems and Structures (RILEM).

The JAI Guest Editor is Andreas T. Wolf, Dow Corning GmbH, Wiesbaden, Germany.

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Preface

What Impact Do Design Choices in the Building Industry Have on Our Destiny?

The global population of *Homo sapiens* reached four billion in 1974, five billion in 1987, six billion in 1999, and seven billion by the end of October 2011. It continues to soar at a rate of 1.1 percent per year and is expected to reach eight billion sometime within the time frame of 2025-2027, and nine billion around mid-century[1].

Whilst the population has increased by a factor of about 2.7 during the past 60 years, the global annual primary energy consumption has grown by a factor of 4.5, a trend bearing the signs of a typical *runaway process*. A worry compounding this symptom is that only a small share of the global population, some 1.2 billion people (approximately 15 percent of the total population) located in the OECD countries, accounts for the lion's share (47 percent) in global energy consumption[2,3]. The developing countries are now eagerly adopting this historically *'proven formula'* for success.

The biosphere, and hence the environment, of planet Earth is self-regulating. If humankind is not capable of simultaneously halting or reversing population growth whilst drastically reducing its average footprint of energy consumption per capita, this *runaway process* will result in an environmental implosion, which will be aided by increasing demand for water, productive land (food) as well as waste generation[4]. The ensuing starvation and environmental disasters will drastically decimate our population to a level that again can be sustained by Earth's fragile (and then damaged) environment. Assuming that we are able to quickly and effectively minimize our impact on the environment, we are still facing an environmental bottleneck in this century.

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[1] Anonymous, *Real time World Statistics*, online at: http://www.worldometers.info/world-population/

[2] Anonymous, *Key World Energy Statistics 2011*, International Energy Agency (IEA), Paris, 2011, available for download at: http://www.iea.org/textbase/nppdf/free/2011/key_world_energy_stats.pdf

[3] Anonymous, *BP Statistical Review of World Energy*, 2011, available for download at: http://www.bp.com/assets/bp_internet/globalbp/globalbp_uk_english/reports_and_publications/statistical_energy_review_2011/STAGING/local_assets/pdf/statistical_review_of_world_energy_full_report_2011.pdf

[4] Anonymous, *The Little Green Data Book*, The World Bank, Washington, D.C., 2011, online at: http://data.worldbank.org/products/data-books/little-data-book/little-green-data-book

Impact of Buildings on the Environment and the Way Forward

One of the principal needs essential for the human race to survive is subsistence, which relies on an unconditional availability of food and shelter. The services involved in the operation of 'modern shelters', i.e., residential and commercial buildings — lighting, heating in the winter, cooling in the summer, water heating, electronic entertainment, computing, refrigeration, and cooking — require a staggering amount of energy. The energy required for the operation of buildings in the U.S.[5] alone corresponds to 42 EJ (1 Exajoule = 10^{18} Joule) or about 1 Giga-ton-oil-equivalent (1 toe = 41.87 GJ). This accounts for almost 40 percent of the total U.S. energy use. This amount is equivalent to the energy released by about 670,000 atomic bombs of the 'Little Boy' type dropped over Hiroshima on August 6, 1945, a bomb that exploded with an energy of about 15 kilotons of TNT (63 TJ).

In addition to the operational energy employed during use, buildings embody the energy used in the mining, extraction, harvesting, processing, manufacturing and transport of building materials as well as the energy used in the construction and decommissioning of buildings. This embodied energy, along with a building's operational energy, constitutes the building's life-cycle energy and carbon dioxide (CO_2) emissions footprint.

Energy efficiency of buildings has been on the agenda of many governments during the past 20 years. However, in order to effectively shrink the ecological footprint of our buildings, we must seek ways to 'decarbonize' our energy sources, i.e., we have to shift from the burning of fossil fuels to energy sources that do not release additional CO_2 to the atmosphere. Renewable energy sources, such as wind, hydro, tide and wave, geothermal, photovoltaic and thermal solar, biomass fuels, as well as synthetic fuels produced, for instance, by genetically modified algae or bacteria or by the Fischer-Tropsch process from existing atmospheric CO_2 are likely to play an increasingly important role in the future energy mix[6,7]. However, this shift towards more benign and renewable energies does not imply that energy efficiency is off the agenda. On the contrary, we have to strengthen our efforts directed at making our buildings more energy efficient. Finally, we have to consider ways of dematerializing as well as rematerializing our buildings. Dematerialization is a

[5] Anonymous, Energy Efficiency Trends in Residential and Commercial Buildings, U.S. Department of Energy, 2008, available for download at: http://apps1.eere.energy.gov/buildings/publications/pdfs/corporate/bt_stateindustry.pdf

[6] Schattenberg, P., "Ancient Algae: Genetically Engineering a Path to New Energy Sources?", ScienceDaily, July 11, 2011, online at: http://www.sciencedaily.com/releases/2011/07/110711164533.htm

[7] Jess, A., Kaiser, P., Kern, C., Unde, R.B., von Olshausen, C., "Considerations Concerning the Energy Demand and Energy Mix for Global Welfare and Stable Ecosystems", *Chemie Ingenieur Technik*, Vol. 83, No. 11, 2011, pp. 1777–1791.

reduction in the bulk (mass) of hardware and the associated embodied energy used in the construction of buildings ("doing more with less"), while rematerialization is the reuse or recycling of building materials at the demolition stage. Both dematerialization and rematerialization recognize that there are finite limits to the amount of materials we can extract from our planet.

The amount of carbon dioxide emissions that construction can influence is substantial. A British report, published in autumn 2010, estimates that construction-related CO_2 emissions account for almost 47 percent of total carbon dioxide emissions of the United Kingdom[8]. The previously cited U.S. EPA report estimates that buildings in the United States contribute 38.9 percent of the nation's total carbon dioxide emissions. Due to the energy inefficiency of the existing housing stock, CO_2 emissions generated during use of buildings in the U.K. account for over 80 percent of total CO_2 emissions. Previous life-cycle energy analyses have repeatedly found that the energy used in the operation and maintenance of buildings dwarf the energy embodied in building materials. For example, Cole and Kernan[9], in 1996, as well as Reepe and Blanchard[10], in 1998, found that the energy of operation was between 83 to 94 percent of the 50-year life cycle energy use. Even for new, highly efficient office buildings located in China, where currently considerably less energy is being consumed by the operation of buildings when compared to the U.S.A. or Western Europe, operational energy accounts for 56 percent of the total life cycle energy[11].

Building construction and demolition are major contributors to the waste we generate. In a report issued in April 2009, the U.S. EPA estimates that 160 million tons of building-related construction and demolition (C&D) debris is generated in the U.S.A. annually, of which 8 percent is generated during new construction, 48 percent is demolition debris, and 44 percent is

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[8] Anonymous, *Estimating the Amount of CO_2 Emissions that the Construction Industry can Influence - Supporting material for the Low Carbon Construction IGT Report*, Ministerial Correspondence Unit, Department for Business, Innovation & Skills, London, United Kingdom, 2010, available for download at: http://www.bis.gov.uk/assets/biscore/business-sectors/docs/e/10-1316-estimating-co2-emissions-supporting-low-carbon-igt-report

[9] Cole, R. and Kernan, P. "Life-cycle Energy Use in Buildings", *Building & Environment*, Vol. 31, No. 4, 1996, pp. 307–317.

[10] Reppe, P. and Blanchard, S., *Life Cycle Analysis of a Residential Home, Report 1998-5*, Center for Sustainable Systems, University of Michigan, 1998, available for download: http://www.umich.edu/~nppcpub/research/lcahome/homelca.PDF

[11] Fridley, D., Zheng, N., and Zhou, N., "Estimating Total Energy Consumption and Emissions of China's Commercial and Office Buildings", Report LBNL-248E, Lawrence Berkeley National Laboratory, Berkeley, CA, USA, 2008, available for download at: http://china.lbl.gov/publications/estimating-total-energy-consumption-and-emissions-chinas-commercial-and-office-building

renovation waste. An estimated 20 to 30 percent of building-related C&D debris is recovered for processing and recycling. The materials most frequently recovered and recycled were concrete, asphalt, metals, and wood[12].

Regardless of one's personal opinion about the consequences of the above facts and statistics for the future of humanity, any rational thinker among us must appreciate the serious cost overhead associated with all this waste. In monetary terms, can the waste laden expenditures of the past continue to be expanded and sustained by humankind in the 21st Century?

21st Century Potential for Positive Change – Contributions by Sealants and Adhesives

What do the previous comments have to do with a book focused on the durability of building and construction sealants and adhesives?

Sealants and adhesives are at the interface between building materials and/or components and provide important functions, such as sealing, bonding, strengthening, movement accommodation, shock protection, fire retention, thermal or electrical insulation, and many others. These functions provide added value to the building and can enable a reduction in the building's ecological footprint. Below are just a few examples of the contributions that sealants and adhesives can make to the reduction of operational energy associated with a building:

- Energy-efficient ventilation achieved via controlled air and moisture flows (elimination of both 'infiltration' and 'exfiltration', the unintentional and uncontrollable flow of air through cracks and leaks in the building envelope).
- Improved thermal insulation of windows achieved by replacement of existing glazing by durable, sealed high performance insulating glass units.
- Renewable energy generation: Use of sealants and adhesives in the assembly and sealing of photovoltaic (PV) solar modules as well as during installation of building integrated photovoltaic solar panels (BIPV) in the building envelope.

The use of a structural sealant or adhesive may also allow redesign of a building component such that the dematerialization results in a reduction of the associated embodied energy of the component.

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[12] Anonymous, *Buildings and their Impact on the Environment: A Statistical Summary*, Revised April 22, 2009, U.S. Environmental Protection Agency, Green Building Workgroup, available for download at: http://www.epa.gov/greenbuilding/pubs/gbstats.pdf

One example is the elimination of steel reinforcement bars in uPVC windows by bonding the glass panes to the uPVC frame as an alternative reinforcement measure. Experience gained with silicones in structural glazing and protective glazing systems and with polyurethanes in automotive direct glazing led to the development of these structurally bonded window systems. Obviously, the strength of the window then depends on the structural strength of the glass unit. However, glass has a good load bearing capability (stiffness) and can contribute considerably to the overall strength of the system. In addition to their environmental benefit (smaller carbon footprint), these constructions also offer functional benefits, such as leaner and more slender frame designs (the larger vision area results in increased light transmission via the window opening and provides improved natural lighting) as well as improved protective glazing properties (resistance to burglars, bomb blasts, hurricanes, earthquakes, avalanches, etc.)[13]. In this example, dematerialization is achieved by satisfying several product functions through one component (sealant) of the overall product (window).

A second example is the replacement of concrete beams by hybrid composite beams. These composite beams are one-tenth the weight of concrete, one-third the weight of steel, yet they are strong enough to replace structural concrete beams. Manufactured by filling fiberglass composite boxes with a concrete and steel arch, covered by composite tops secured using a two-part methacrylate adhesive, they show excellent environmental durability and are expected to have a useful life of at least 100 years, during which they need less maintenance than existing materials. Furthermore, due to their resilient, energy absorbing, construction, they provide seismic shock resistance[14]. The 'dematerialized' components mentioned here in the two examples can lower the carbon footprint of construction projects due to the reduction in their materials' embodied energy, and the lower fuel usage needed to ship these lighter weight components.

Design Choices Involving Sealants and Adhesives in Building Construction and Their Impact on our Environmental Footprint

Whether sealants and adhesives will be seen from an ecological point of view as being part of the solution or part of the problem – especially when one considers recycling of materials and components at the renovation or demolition stage – depends largely on decisions made during the design phase.

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[13] Wolf, A.T., "Sustainability Driven Trends and Innovation in Glass and Glazing", 2009, available for download at: http://www.dowcorning.com/content/publishedlit/sustainability_driven_trends_and_innovation_in_glass_and_glazing.pdf

[14] Anonymous, "Attaching Hard-to-bond Construction Materials for Innovative Performance", online at: http://www.specialchem4adhesives.com/home/editorial.aspx?id=5505&lr=mas12184&li=10020918

First, it should be recognized that, even if the design process itself had only a minor contribution to the cost of building, a considerable portion of the cost (as well as material and energy use) associated with later life cycle phases is committed at the design stage. It has been estimated that more than 80 percent of a product's environmental impact is determined during its design phase[15], and it is likely that the same holds true for buildings. Therefore, it is essential to consider environmental aspects of the whole buildings as well as of the components and materials used from the first stages of design and development. Such an approach is generally termed 'Eco-innovation' or 'Design for Environment (DfE)'. The purpose of Design for Environment then is to design a building in such a way as to minimize (or even eliminate!) the environmental impacts associated with its life cycle. Design for Environment, as applied to buildings, typically focuses on energy efficiency and effectiveness, materials innovation, and recycling. While energy efficiency often is understood as addressing energy savings at the sub-system level, for instance in terms of the heating, ventilation and cooling (HVAC) system, energy effectiveness may be defined as producing the best overall results with the least amount of energy. Materials innovation addresses the need to develop new materials that allow construction of low embodied energy, light weight, and durable components which also meet the need for improved recyclability (which often is a challenge with composites) and have less environmental impact. Recyclability finally is considered at the design stage by 'Design for Deconstruction (DfD)'. Design for Deconstruction is an emerging concept that borrows from the fields of design for disassembly, reuse, remanufacturing and recycling in the consumer products industries[16,17]. According to the ISO 14021:1999 standard "Environmental labels and declarations - Self-declared environmental claims (Type II environmental labeling)", the use of the term 'design to disassemble' refers to the design of a product that can be separated at the end of its life-time, in such a way its components and parts are reused, recycled, recovered as energy form, or in some other way separated from the remainders flow. The overall goal of Design for Deconstruction is to reduce pollution impacts and increase resource and economic efficiency in the adaptation and eventual removal of buildings, and recovery of components and materials for reuse, re-manufacturing and recycling. From

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[15] Knight, A., "The New Frontier in Sustainability – The Business Opportunity in Tackling Sustainable Consumption", BSR, San Francisco, USA, July 2010, available for download at: http://www.bsr.org/reports/BSR_New_Frontier_Sustainability.pdf

[16] Guy, B. and Shell, S., *Design for Deconstruction and Materials Reuse*, available for download at: http://www.recyclecddebris.com/rCDd/Resources/Documents/CSNDesignDeconstruction.pdf

[17] Steward, W.C. and Baum-Kuska, S.S., "Structuring Research for 'Design for Deconstruction'", *Deconstruction and Building Materials Reuse Conference*, 2004, available for download at: http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.195.573&rep=rep1&type=pdf

an environmental point of view, building adhesives and sealants often face two contradicting requirements: On the one hand, these materials should be durable and resist the environmental stressors, such as sunlight, water, and heat; on the other hand, there is the need to easily separate substrates for recycling or repair. Recently, there has been increased interest in 'Debonding on Demand', which refers to the process of easily separating two adhered surfaces. Heat and light switchable adhesives have been developed, as well as primers that can act as a separation layer when activated by infrared or microwave radiation[18,19,20]. Surely novel methods for Debonding on Demand will be developed in the near future and it will be interesting to see what the environmental durability of these sealants and adhesives will be.

Returning to the topic of dematerialization, it should be noted that less material use does not automatically imply less environmental impact. If the dematerialized product or component is inferior in quality and has a shorter usable life, then more replacements will be needed during the overall life of the building, and the net result likely will be a greater amount of waste in both production and use. Design for Dematerialization, therefore, must always be accompanied by Design for Reliability and Durability, i.e., designing a product or component to perform its task in a reliable, consistent manner, and ensuring that it will also have a long life span. From an environmental viewpoint, therefore, dematerialization should perhaps be better defined as the reduction in the amount of waste generated per unit of building product.

When considering Design for Durability, a fair question to ask is: What should be the design life of a building or a material or component used in the building? Clearly, there is a trade-off between the embodied energy in the building and its energy efficiency and effectiveness. Building components that are still far from being fully optimized in terms of their impact on energy efficiency should not last forever; rather they should be easily replaceable with new, more efficient components and easily recycled at the end of their life. Obviously, the corollary to this statement is that the higher the energy efficiency associated with a building component is, the higher its expected service life should be. The same holds true from an economic point of view: The higher the investment cost, the longer it takes to recover the invest-

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[18] Jacobsson, D., "Strong Adhesion to Fragile Surfaces – Debonding on Demand", online at: http://www.adhesivesmag.com/Articles/Green_Recycling/BNP_GUID_9-5-2006_A_10000000000000679822

[19] Manfrè, G. and Bain, P.S., "Debonding TEM technology for reuse and recycling automotive glazing", *Glass Performance Days*, 2007, pp. 791–796, available for download at: http://www.glassfiles.com/library/3/article1162.htm

[20] Anonymous, "Reversible glue 'de-bonds' at the touch of a button", Royal Society of Chemistry (RSC), 2006, online at: http://www.rsc.org/chemistryworld/News/2006/July/26070601.asp

ment, the higher the durability of the component should be. Consequently, recyclability is more important for short-lived products and components than for more durable ones.

Another, very effective approach to dematerialization is moving from a product to a service orientation, i.e., using less material to deliver the same level of functionality to the building owner. After all, building owners and users are more interested in the value a product provides than in its physical presence. For example, the newly published ASTM Standard C 1736-11 “Practice for Non-Destructive Evaluation of Adhesion of Installed Weatherproofing Sealant Joints Using a Rolling Device” offers the sealant applicator an opportunity to move from installation contracts to product-oriented service contracts. Probably most applicators will initially view the concept of inspecting the quality of installed joint seals as challenging their reputation, possibly resulting in increased liability for them. However, when this inspection is offered as part of a periodic maintenance contract, sealant failures can be repaired locally and without replacing the entire installation. Such maintenance results in material savings as well as satisfied building owners (and facility managers), as the functionality of the seals is ensured and maintained at a high level, and, ultimately, also results in better and more stable relationships between sealant applicators and their clients due to the more frequent contacts and the higher value provided. Similarly, sealant manufacturers initially will be concerned that such service contracts will lead to decreasing sealant product sales. However, revenue models could be developed that allow extension of sealed joint warranties based on certification fees associated with the inspection of the building.

Choosing Energy Effectiveness Rather than Efficiency

In order to be energy effective, it is important to look at the Life-Cycle Analysis (LCA) to see what lifecycle stage (material production, manufacturing, use, end-of-life) has the greatest environmental impact. It is important to focus efforts first on this stage before dedicating time to the others. Operational energy reduction is a key priority, since the *most sustainable energy is energy saved*. Energy itself is not of particular interest, but rather is a means towards desired ends. Clients desire the services that energy can deliver, for instance, comfort, illumination, power, transportation - not energy by itself. Hence, maximum energy efficiency with minimal environmental impact is the architectural challenge that ultimately allows us to “have our cake and eat it too”. In this context, material choices that impact operational energy are important, while they are less significant for the energy spent in manufacturing, construction and demolition of the building.

Therefore, two of the key objectives in designing sustainable buildings are to lower the operational energy consumption and the life-cycle costs of the building. This should be achieved by:

- First, focusing on improving the performance of the building envelope in order to lower the energy demand, as the life span of the envelope is between 50 and 100 years. Commonsense already tells us to focus on things such as air tightness of the building envelope, the quality of the insulation and especially of the windows, and to avoid thermal bridges.
- The second priority then should be to avoid energy use, for instance, by using efficient appliances and through the increased use and conversion of energy embedded in natural day-lighting (the ultraviolet and infra-red fractions).
- Once this has been accomplished, the focus should shift towards the generation of energy from 'renewable' source, as the life span of these systems is in the 10-25 years range. This approach is also dictated by simple economic considerations, as more capital is needed for an oversized renewable energy system to compensate for a poorly designed building envelope or for inefficient appliances.

In building, the most technically appropriate materials will lower operational energy costs over the life cycle of a building and demonstrate excellent durability. For example, composite materials involving carbon fibers or ceramic compounds may have a relatively high embodied energy, but when they are used appropriately, they can save energy in a building's use-phase due to their advanced physical properties, e.g., insulation, strength, stiffness, heat or wear resistance.

Choosing Wisdom over Intelligence

Energy effectiveness also requires 'Intelligent Design' – meant here as a consideration of all interactions at the highest system level and anticipating unexpected side-effects. For instance, some poor designs meant to improve energy efficiency of buildings have led to major problems in terms of comfort and health for the building occupants. As mentioned earlier, reducing air leakage from the building envelope and ductwork is typically among the most substantial improvements that can be made to reduce operational energy use. Sealing the building envelope leads to a reduction in the air exchanges previously achieved by 'natural ventilation'. The desired effect is a reduction in the HVAC operational energy. However, when poorly designed, the undesired side-effect is an increase in potentially harmful volatile organics, radon, moisture and mold growth, with negative impact on the comfort and health of the building occupants. On the other hand, when properly planned by combining air tight envelopes with mechanical ventilation systems having integrated heat exchangers, very low operational energy consumption can be achieved, down to the level of 'passive house' standard, while at the same time providing good air quality to the building occupants.

The challenges both designers and businesses face when moving from traditional design and production methods to ones that promote a sustainable future are huge. For the designer, it is important to appreciate, what building owners really want: *Sustainability, but not at the expense of performance and aesthetics*! Designers who balance and optimize the technical and aesthetic life-span requirements for a building product or component with the environmentally related characteristics and performance attributes can reduce the energy and materials dedicated to these requirements.

The adhesives and sealants industry as well as academia will choose wisely if they seek out the *environmental attributes* that can be delivered by their products with the key aim of lowering the operational energy consumption and the life-cycle costs of the building. Enhancing a product's function and life span with the added benefit of improving its environmental profile and impact should be a key focus in future research and development efforts. More effort can be put into the design phase of building materials, such as adhesives and sealants, building components, building systems, and finally *the whole building* to truly achieve improved sustainability. As highlighted a number of times in this preface, durability and sustainability are related in different ways and at different levels. As an industry, will we choose wisely? Will we see more papers and presentations on this topic at one of the future Durability of Building and Construction Sealants and Adhesives symposia?

Maybe 'Intelligent Design' is not an adequate term anyway. Intelligence predicts the success of individuals without regard to the consequences of their success to others. Wisdom, however, reflects the ability to make adaptive decisions in a social context. It requires altruism, balanced judgment, competent reality testing, and a *consistent view of the big picture*. This is why wisdom, not intelligence, applies to the survival of species[21].

What we must strive to achieve is sustainability, supporting the long-term ecological balance, certain in the knowledge that "the *most sustainable energy is the energy saved*". 'Wise Design' takes this fundamental truth into account, and has the potential of truly living up to the expectations of Carolus Linnaeus, the father of modern biological classification (taxonomy), who in 1758 applied the name *Homo sapiens* (Wise Man) to our species.

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Wiesbaden, Germany

[21] Watson, D.E., *Is Homo sapiens sapiens a Wise Species?*, online at: http://www.enformy.com/$homosap.html

Overview

Introduction

The Fourth ASTM International Symposium on Durability of Building and Construction Sealants and Adhesives (2011-DBCSA) was held on June 16–17, 2011 in Anaheim, California. It was sponsored by the ASTM International Committee C24 on Building Seals and Sealants in cooperation with the International Union of Laboratories and Experts in Construction Materials, Systems and Structures (RILEM). The symposium was held in conjunction with the standardization meetings of the C24 Committee. With presentations from authors representing nine countries in North and South America, Europe, Asia, and Australia, the symposium was a truly international event.

As in the previous events of this symposium series, the 2011 symposium brought together architects, engineers, scientists – researchers and practitioners. One of the stated goals of the symposium was to transfer new ideas, gained from laboratory research and field work, to the study of sealant and adhesive durability and the development of new products and test methods. The symposium provided an excellent forum for international experts to share and compare their experiences, network with their peers, and exchange best practices with regard to the durability testing and assessment of building and construction sealants and adhesives. It also provided a platform for an expert panel discussion. The panel discussion was originally conceived as a discussion on sealant warranty issues, but became a spirited conversation regarding the impact of the newly developed ASTM C1736 Standard Practice with participation by the panelists, ASTM C24 members, as well as presenters and participants of the international symposium. Perhaps the greatest value of this series of symposia lies in the discussions occurring during these events and in the utilization of the resulting information.

The current series of ASTM symposia on Durability of Building and Construction Sealants and Adhesives is a continuation of tri-annual symposia which were inaugurated by the RILEM Technical Committee 139-DBS Durability of Building Sealants in 1994. Today, this continuing series of symposia provides the best scientific forum globally in the building and construction industry for peer-reviewed papers on all aspects of sealant and adhesive durability. Furthermore, data presented at those symposia over the past 17 years have been the single most important factor influencing ASTM International and ISO standards as well as RILEM technical recommendations related to construction sealant durability.

In several languages, such as Dutch, Finnish, Romanian or French, *sustainable* is translated as *durable*. This synonymous use of *durable* and *sustainable* is not surprising, as durability plays a key role in achieving sustainable construction, because "one way of extending resource productivity is by extending the useful life of products" (DeSimone & Poppof, 1998). The increased utilization of sustainable construction practice, i.e., designing for durability by utilizing building science and life cycle analysis as its foundation, as well as mandatory government regulations, such as the European Construction Products Directive, have elevated the importance of the durability and service life performance of building and construction sealants and adhesives. All products, not just those involved in safety-critical applications, must demonstrate durability as part of their fitness for purpose assessment. Life cycle costing considerations increasingly drive investment decisions towards products and systems with longer service life cycles and lower maintenance costs.

Against a background of national and international efforts to harmonize testing and approval of building materials and structures, ASTM International and RILEM have been looking for ways of bringing together the experience of international experts active in the application and testing of building and construction sealants and adhesives.

As with most scientific disciplines, substantial advances often occur through a series of incremental steps, each contributing pieces of the puzzle, rather than in giant leaps. This is also the case for the papers presented at the Fourth International Symposium on Durability of Building and Construction Sealants and Adhesives (2011-DBCSA). Many of the papers reflect progress reports on on-going research. At the 2011-DBCSA symposium, we saw several examples of the steady progress being made by leveraging these scientific advances into a new generation of test methods as well as assessment practices.

This book contains twenty-three of the twenty-seven papers presented at the symposium as well as two papers submitted only for publication in the proceedings. It also contains an editorial summary of the panel discussion. The contributions condensed in this STP volume represent state-of-the-art research into sealant and adhesive durability and reflect the varying background, experience, profession, and geographic location of the authors. The following major themes are evident in this collection:

- Laboratory Testing and Specialized Outdoor Exposure Testing
- Factors Influencing the Durability of Sealed Joints and Adhesive Fixing
- Development of New Test Methods and Performance-Based Specifications
- Field Experience with Sealed Joints and Adhesive Fixing
- Performance under Seismic Loads

Overview of Papers

Below is a short overview of the papers published in this volume with regard to the above five categories.

Laboratory Testing and Specialized Outdoor Exposure Testing

Over the last decade, the use of fiber-reinforced polymer (FRP) composites as construction materials in structural engineering applications has grown substantially. Also known as advanced composite materials (ACMs), these materials have proven themselves to be especially valuable for use as main components in hybrid structural members. However, in order to fully capitalize on the high tensile strength of the FRP materials, an effective connection mechanism between the FRP and the conventional building material must be operational at the interface in order to achieve optimum performance of the hybrid structural members. **Chen** and **El-Hacha** in their paper investigate the bond performance between glass-fiber reinforced polymer (GFRP) plates and cast-in-place ultra-high-performance concrete (UHPC) using an epoxy-based adhesive filled with coarse silica sand aggregates. Both shear and tensile tests are conducted using three different types of epoxy adhesives. Analysis of the experimental data shows that the specimens bonded with the moisture tolerant epoxy adhesive intended for bonding of hardened concrete and steel performs the best.

The use of glass in the building industry is increasingly extended beyond its space-enclosing function to structural applications, such as in glass beams, glass columns or bracing façade elements. Recently, interest in I-shaped bonded hybrid steel-glass beams as transparent structural elements has grown. In these beams, steel flanges and glass are connected by a linear adhesive bond. The coupling between steel and glass substantially increases the flexural strength of the glass beams due to the shear forces being transferred via an adhesive bond. In their contribution, **Feldmann**, **Abeln** and **Preckwinkel** study the behavior of adhesive joints in hybrid steel-glass beams by means of simplified small scale tests. The results show that full-scale hybrid beams with butt splice bonded and U-bonded geometries are feasible using suitable load-bearing adhesives. However, careful design of the joints is required, taking the specific properties of the adhesive (brittleness, weather resistance, etc.) into consideration.

Autoclaved aerated concrete (AAC), also known as autoclaved cellular concrete (ACC) or autoclaved lightweight concrete (ALC), was invented in the mid-1920s in Sweden and has recently gained some reputation as a green building material, because of its thermal insulation property. In Japan, high-performance water-borne acrylic sealants are traditionally the sealant product of choice for use between ALC panels. While the degradation mechanisms of acrylic sealants are well known, their resistance to outdoor weathering has not yet been fully investigated. **Miyauchi**, **Lacasse**, **Enomoto**, **Murata** and **Tanaka** study the long-term behavior of these sealants by on-site investigation of acrylic sealed external joints of ALC-clad buildings as well as by outdoor exposure testing of different types of acrylic sealants in three climate regions located in Japan. As expected, the aging of these sealants, as determined by the degree of surface cracking, depends on the local temperature and the respective degree of exposure to solar radiation. Also not surprisingly, joint configurations with two-sided sealant adhesion, installed in deep panel ALC cladding, are more reliable than three-sided adhesion joints used for thin panel ALC cladding in terms of the durability of the sealed joints installed in actual buildings. However, what does surprise is the substantial amount by which the elongation of the three-sided adhesive joint configurations decreases after five years outdoor exposure and the associated large number of sealed joints with ALC substrate failure.

The durability of sealed or bonded joints is dictated by many factors such as joint design, surface preparation, application, formulation, joint movement, and weather. **Schueneman**, **Hunt**, **Lacher**, **White** and **Hunston** attempt to address the link between formulation and weathering durability by monitoring changes in apparent modulus during exposure to outdoor weathering and cyclic strain. Cyclic movement is accomplished via custom built systems that apply cyclic strain. The conditions for simultaneous exposure to strain and weathering are chosen such as to simulate wood (cold compression) and concrete/metal (hot compression) construction materials. A key finding of their research is that changes in apparent modulus are primarily driven by underlying changes in compression set, a potentially critical contributor to stress in structures during rapid temperature changes.

In their paper, **Sitte**, **Brasseur**, **Carbary** and **Wolf** report on the preliminary evaluation of a novel transparent structural silicone adhesive (TSSA) developed for point fixing in glazing. The paper presents information on the durability and physical properties of the new material and suggests a methodology for deriving static and dynamic design strength values for the new material based on creep rupture experiments as well as nondestructive dynamic load experiments using the stress whitening phenomenon observed with this material as the limit state. The paper further discusses material characterization and hyperelastic modeling used in the finite element analysis based on finite strain theory.

The Institute of Building Construction at Dresden's Technical University is one of Europe's leading research facilities focused on the study of glass in buildings. **Weller** and **Vogt** describe some of the research activities carried out at this institute on bonded glass connections for load-bearing structures. Examples of the research covered are bonded point supports for overhead glazing and for large photovoltaic modules subjected to high environmental loads, linear adhesive joints for hybrid steel-glass composite beams with good ductility and for glass fins with a reduced cross-section in minimized steel-and-glass facades, as well as bonded joints for photovoltaic facades and for an all-glass pavilion.

Further research at the same institute is highlighted in a paper by **Weller**, **Nicklisch**, **Prautzsch** and **Vogt** that outlines the testing and evaluation program used in the selection of adhesives for transparent bonded joints in all-glass load-bearing structures of two buildings located in Dresden and Grimma, Germany. The test and evaluation program designed by the institute led to individual approvals of these constructions by the German building code authority. The authors describe the various stages of this project from the evaluation of material properties of various adhesives to the optimization of the bonded joint geometry in order to achieve long-term integrity of the structures.

Recent years have seen a multitude of new sealant and adhesive products based on novel polymers, cure chemistries, and formulations being launched onto the market for which there is a lack of experience in terms of performance histories for similar products. An accurate service life prediction model is urgently needed for building sealants to greatly reduce the time-to-market of a new product and reduce the risk of commercializing a poorly performing product. A key element in any accelerated weathering test is the precise control of all environmental variables in the laboratory test apparatus in order to produce reliable weathering data that can be used to generate a predictive model. In their contribution, **White**, **Hunston**, **Tan**, **Filliben, Pintar** and **Schueneman** report on a systematic study investigating individual and synergistic impacts of four environmental factors (cyclic movement, temperature, relative humidity, and ultraviolet radiation) on the durability of a model sealant using a novel laboratory test apparatus. The apparatus not only allows precise control of the environmental factors, but it also permits in-situ characterization tests of the specimens.

Factors Influencing the Durability of Sealed Joints and Adhesive Fixing

While our understanding of the factors that determine the service life of sealed or bonded joints has progressed substantially over the past decades, there is still much research needed on the durability and reliability of novel structures, components or designs. Several papers at the symposium focus on this topic.

Bent or warped glass allows turning a typical glass-and-metal curtain wall design into an exciting, innovative architectural statement. Traditionally, curved glass is manufactured from float glass by heating it to a temperature above the softening point and then shaping the glass in a mould. Since this technique is time and energy consuming and consequently relatively expensive, cold-bending has been developed as a more affordable alternative. In this glazing technique, flat glass panes are bent to the desired shape on a curved frame and then mechanically or adhesively attached to the frame. The cold-bending process implies that the glass becomes permanently subjected to bending stresses during its lifetime. Glass on contemporary curtain wall projects is mostly insulating glass which raises concerns about the longevity of cold bent insulating glass (IG) units, as the bending process induces a shearing action to both the primary and secondary edge-seals. While very little scientific information on this topic has been generated in the past, the number of building projects involving cold-bent insulating glass globally continues to increase rapidly. In their land-mark paper, **Besserud**, **Bergers**, **Black**, **Carbary, Mazurek, Misson** and **Rubis** describe testing protocols designated to determine the effect of cold-bending on the durability of the insulating glass unit as measured by argon retention, frost point change, and visual changes after aging. As part of the experimental protocol, first the bending behavior of a full size IG unit is assessed, which is then modeled to predict the stresses and strains on the primary and secondary seals. Small (standard) size IG units are then tested according to the ASTM E2188-10 and E2190-10 protocols while simultaneously subjecting them to an edge seal displacement in all three directions that induces equivalent stresses in the edge seal. Argon retention and frost point measurements are taken before and after the durability testing and results reported. The methodology developed in this research provides a strong foundation for future testing in the area of cold-bent IG unit durability.

Durable, reliable, and high strength adhesion of elastomeric sealants and adhesives to a variety of substrates is essential to a broad range of industries. In their paper, **Gutowski**, **Toikka** and **Li** discuss and experimentally verify the principles of engineering substrate surfaces through grafted connector molecules. The authors demonstrate that the incorporation of silicon-based and/or amine-terminated graft molecules such as silanes or polyethylene-imines, at the polymer interface, results in the formation of strong molecular links between a range of organic and metallic substrates and elastomeric sealants or adhesives, leading to significantly improved bonding. The technology has been successfully adopted by the global automotive industry for improving adhesion of a variety of adhesives and coatings to polyolefinic substrates.

The bonding of point-fixed supports for glazing has recently received increased attention, as in contrast to mechanical fixation, bonding of point supports offers a number of advantages, such as no or lower visibility of the supports from the exterior, a ‘smooth’ transfer of the load into the glass pane (avoiding stress peaks), and the elimination of drilling holes from the glass. Failure mechanisms under typical loading conditions and parameters that affect failure probability, mode, or mechanism are the focus of ongoing investigations. **Hagl** studies the mechanical characteristics of degraded silicone-bonded point supports with axial geometry undergoing tensile loading. Tensile loading of bonded point supports is considered the critical load case, as dynamic loads, such as wind load, subject the adhesive to out-of-plane loads. In the paper, the following parameters are investigated in their effect on the durability of point supports bonded with a two-part adhesive: (a) incorrect mixing ratio of the adhesive components, (b) inhomogeneous mixing due to insufficient or improper mixing procedure, (c) fatigue degradation of the adhesive, and (d) local defects in the bond, e.g., caused by inclusion of bubbles or by partially failed adhesion. The main motivation for this kind of research is to strengthen the confidence of building code authorities in the durability of bonded designs.

As mentioned earlier, there is an increased interest in the cold-bending of glass in order to realize curved or warped glass façades. However, cold bending induces permanent stresses in the glazing structure, especially in the corner area of the glass units. Dynamic or static loads acting perpendicular to the glass surface, such as wind or snow loads, also cause high stresses in the corner area. **Hagl** and **Dieterich** present numerical results of a parametric study for pressure-loaded glass units with a focus on corner loads and stresses. The results show that the stress levels in the corner areas might exceed the design stress values used for sizing the bond geometry.

Blistering of sealed or bonded joints is as a form of degradation. Sometimes blistering is observed when exposure to direct sunlight occurs immediately after application of the sealant or adhesive on an unusually hot day. Often this case of blistering can be attributed to intrusion of air or moisture from voids within the substrate into the sealant or adhesive. While other causes of blistering exist, blistering driven by the diurnal variation in temperature is an important aspect of the degradation of sealed or bonded joints. The paper by **Hailesilassie** and **Partl** deals with the mechanism of asphalt blistering on concrete bridges. While the focus of their paper is on blistering in asphalt overlays, their findings are relevant to the sealant and adhesive industry. According to the authors, blistering is a major problem in asphalt covered concrete structures, such as multi storage parking buildings, built-up roofs, tunnels, pedestrian areas or concrete bridge decks. In this particular research, a linear viscoelastic finite element model is developed to simulate time dependent blister growth in the asphalt layer under uniformly applied pressure with and without temperature and pressure fluctuation. The finite element model simulation shows that the daily temperature variations may have a significant influence on blister growth in asphalt pavements. The authors conclude that temperature fluctuation has more influence on blister growth than fluctuation of the pressure inside the blister.

Joints may fail because of degradation of either cohesive or adhesive properties of the sealant or adhesive. Since silicone materials display excellent bulk durability, adhesive failure mode is the more likely cause of joint failure. Interfacial adhesion can be improved either by modifying the formulation of the sealant or adhesive or by modifying or treating the surface of the substrate, for instance, by plasma treatment or use of a primer. **Vandereecken** and **Maton** report on a comparative study evaluating the adhesion improvement observed for a two-part silicone adhesive on a variety of substrates either by applying a wet primer or the dry Pyrosil® flame treatment. Pyrosil® is a pyrolytic chemical pre-treatment process that forms an amorphous, nano-scale silicate layer on the treated surfaces. In this process, the targeted surface is treated with the front (oxidizing) section of a flame obtained by burning a silane, propane, and butane mixture in a pen-like torch. During the combustion process, the silane is oxidized to form SiO_2 nano-particles which cover the surface with an ultra-thin (20 - 40 nm) strongly adhering silica coating.

Development of New Test Methods and Performance-Based Specifications

The weatherability of construction sealants is a highly important performance criterion for the prediction of their aesthetic and functional service lives. Currently, the evaluation of a sealant's surface degradation is carried out mainly by qualitative visual assessment against pictorial references. **Enomoto**, **Ito** and **Tanaka** present information on the weatherability of construction sealants based on a recently developed test specimen design that allows simultaneous exposure of the sealant to forced compression and extension movement in a single specimen with cyclic movement and weathering carried out simultaneously. A quantitative method for the assessment of surface cracks is employed and the relationship between outdoor and accelerated weathering exposure is evaluated by using metrics that indicate the degree of surface cracking as a new semi-quantitative criterion of surface degradation.

Recently, ASTM International published a standardized methodology suitable for the evaluation of joint seal continuity, ASTM C 1736-11 Standard Practice for Non-Destructive Evaluation of Adhesion of Installed Weatherproofing Sealant Joints Using a Rolling Device. This standard practice was created under the jurisdiction of ASTM committee C 24 on Building Seals and Sealants, and the direct responsibility of Subcommittee 30 on Adhesion. It was approved shortly before the symposium on July 1, 2011. In his paper, **Huff** discusses some of the technical questions raised during the development of this standard.

Today there are fifty-nine completed buildings globally that stand over 300 meters tall, a height generally considered super-tall, and dozens more are under construction or being planned. The trend towards super-tall buildings is driven by scarcity of available land, economic prosperity with dramatic population growth within the big cities, and high economic value of the super-tall buildings. Nowhere is the trend towards super-tall buildings more evident than in Asia, especially in China and South Korea, as well as in the Middle East. Structural silicone glazing is a curtain wall technique commonly used in South Korea and this glazing method is also considered for many of the future super-tall buildings. However, there is no industry-wide guideline or specification for structural silicone sealants in South Korea. In order to prepare for such a specification, **Jung**, **Hahn** and **Lee** report on a comparative evaluation of locally available structural silicone sealants that employs artificial weathering protocols adapted from various global industry standards, such as ASTM C1135 and EOTA ETAG 002. While silicones in general are known to have excellent resistance to weathering, some silicone products included in the study still show noticeable degradation of properties, since the weathering performance of a sealant is affected by its overall composition and not just by its polymer type.

The strength of autoclaved lightweight concrete (ALC) is evidently lower than that of traditional concrete. When movement occurs at a sealed joint between ALC panels, the sealant is required to deform without causing damage to the ALC substrate. However, there is currently not sufficient information permitting the selection of suitable sealants for ALC substrates. **Miyauchi**, **Lacasse**, **Murata**, **Enomoto** and **Tanaka** report on a study comprising both static and dynamic tests carried out to obtain an indication of the modulus of a sealant that can be expected to provide long-term performance when applied to an ALC substrate. Using two-part polyurethane sealants of different elastic modulus, the authors determine the relationship between shear and tensile stresses and the type of joint fracture. The results reveal that the ALC substrate is increasingly likely to fail when the sealant stress exceeds about 0.6-0.7 MPa.

The design criteria for structural silicone glazing (SSG) applications require adhesive systems that maintain their functionality for longer than twenty years in actual field installations. Silicone sealants have well demonstrated their ability to effectively and reliably perform in long-term exterior structural applications. The first-ever four-sided SSG facade, completed in 1971, is still operational today. Still, estimation of the service life of SSG systems based on accelerated testing is difficult, since, in principle, it is necessary to test to failure in order to allow service life prediction, which, for systems designed for long-term durability, imposes practical difficulties. Further complications arise during the transfer of information gained on small scale test specimens to the actual performance of SSG systems as a whole. In his paper, **Recknagel** makes an attempt at adapting dynamic-mechanical material analysis for the performance characterization of structural silicone sealants. The results obtained are reported and discussed for three structural silicone sealants, and characterize their temperature-, deformation- and frequency-dependent behavior. The applicability of the dynamic mechanical material analysis approach and of its various complex test modes for the exploration of the technical performance and the estimation of fatigue life is evaluated for the three sealants investigated. The author intends to complement the dynamic-mechanical assessment methodology with suitable system tests on a section of a structural glazing system that will be subjected to a simplified load function representing the superposition of actual loads acting on the system. The technical fundamentals and the procedure proposed for the development of adequate system tests are discussed.

As already described for the Enomoto et al. paper, the durability of building joint sealants is generally assessed using a descriptive methodology involving visual inspection of aged specimens for defects. This methodology has inherent limitations and the results are qualitative in nature. **White**, **Hunston** and **Tan** propose a new test method that utilizes stress relaxation to evaluate changes in the viscoelastic behavior occurring in sealants during durability testing. In particular, changes in the time dependence of the apparent modulus can be observed and related to molecular changes in the sealant. According to the authors, such changes often precede the formation of cracks and the ultimate failure of the sealant. The paper compares results obtained with the new test method and the currently used descriptive methodology.

During the symposium, a panel discussion was held regarding the impact of the newly developed ASTM C1736 Standard Practice for Non-Destructive Evaluation of Adhesion of Installed Weatherproofing Sealant Joints Using a Rolling Device. The panel consisted of three members of ASTM C24 committee, who had direct involvement with the creation, oversight, and/or passage of C1736, plus one panelist representing a sealant applicator. Context to the discussion is provided by the editor, who has added a short introduction to the topic.

Field Experience with Sealed Joints and Adhesive Fixing

Over the last decade, changes in environmental protection regulations have necessitated reformulation of many historically durable adhesives used in the application of flooring materials. Solvent-borne adhesives with high content of volatile organic compounds (VOCs) were replaced with water-borne or 100% solids adhesive formulations. **Nelson** and **Hopps** suggest that these new environmentally friendly adhesives are less durable and more susceptible to moisture-related deterioration. If the concrete is not properly sealed or allowed to dry, the moisture permeating through or contained in the concrete slab can re-emulsify moisture-sensitive flooring adhesives. Consequentially, applied flooring materials can delaminate, buckle, blister, and crack. The paper compares the properties of the newer moisture-sensitive flooring adhesives with those of their VOC-containing predecessors, and describes the properties of the adhesives that reduce overall durability. It also presents case studies of flooring failures resulting from moisture-related deterioration of adhesives for various flooring materials including carpet tile, sheet vinyl, and vinyl composition tile flooring.

Foamed adhesives are used to join roofing assembly components to the roof substrate and to each other. A variety of performance problems with foamed adhesives as installed in roofing assemblies have led to assembly failures. **Slick**, **Piteo** and **Rutila** present several case studies that illustrate excessive moisture in roofing assemblies or substrates as an issue that contributes to adhesive failure of the roofing assembly.

Performance under Seismic Loads

Buildings exposed to seismic loads pose a severe threat to life and safety of pedestrians as components of the cladding or curtain wall may fracture, dislodge, and fall down. The seismic performance of architectural glass installed in the fenestration section of curtain walls is of special interest, as glass is brittle and may crack, which increases the probability of catastrophic failure, culminating in the fallout of the entire unit. In light of the extensive use of architectural glass in seismically active geographies, anecdotal evidence suggests that the actual performance of glazing during earthquakes is relatively good, as only few serious casualties associated with curtain wall problems are reported. The U.S. National Institute of Building Sciences in their Seismic Safety of the Building Envelope Report (Arnold, 2009) attributes the relative good performance of glass and metal curtain walls to the inherent strength of glass, the flexibility of the framing assembly, the resiliency of the glass retention materials, and the relatively small size of the glass panels. However, historically the sizes of the glass panes have increased and novel methods of glass attachment, such as structural silicone glazing (SSG), have become commonplace. The fact that the load transfer between the glass and the framing system in a SSG curtain wall must occur through the sealant implies that the seismic response of SSG systems is most likely different from systems that are dry-glazed. Recent studies of the seismic performance of various SSG curtain wall configurations were focused on the identification of the failure limit states associated with glass in SSG assemblies. The seismic performance of curtain wall systems is generally assessed in dynamic racking tests on curtain wall mockups

In their paper, **Broker**, **Fisher** and **Memari** present the results of a study in which four-sided structural sealant glazing (SSG) insulating glass curtain wall units were subjected to cyclic racking test methods in accordance with AAMA 501.6 testing protocols. The drift capacity of the system in terms of glass attachment and sealant performance is reported in detail for different levels of racking displacements and boundary conditions. The overall behavior of the system is characterized, and specifically the sealant performance at a corner condition during racking drift is discussed. The damage to the structural silicone sealant is evaluated using visual observation before and after cyclic racking. The authors discuss proposed acceptable sealant stress levels for seismic SSG design and present sealant test results, which show the modulus stability and durability of silicone sealants.

A law in California is mandating earthquake resistance of all hospitals by 2013. California Pacific Medical Center (CPMC) has been planning the new Cathedral Hill Hospital in Downtown San Francisco as a LEED Silver-rated building in conformance with this law. When complete, this 100,000 m^2, fifteen-story, 555-bed hospital will fill a whole city block. The curtain wall system for this building is primarily of a unitized design employing a four-sided structural silicone glazing system. In order to ensure satisfactory seismic performance of the curtain wall system for this project, dynamic racking tests were carried out according to AAMA 501.6 procedure. In their paper, **Memari**, **Fisher**, **Krumenacker**, **Broker** and **Modrich** discuss the results of these dynamic racking tests carried out on curtain wall mockups with regard to the behavior of the glass, framing, connections, and the structural silicone. Tensile stress-strain test results on the structural silicone sealant at selected temperatures and after ultraviolet (UV) light exposures are discussed, and comparisons to the finite element analysis results are presented. Finally, the allowable stress in seismic design of four-sided SSG systems is discussed in light of new information generated for this project.

The 8.8 Magnitude earthquake that shook Chile at 3:34 a.m. on Saturday, February 27, 2010, was one of the most devastating in the history of the country. The earthquake was felt in most parts of Chile, Argentina and some parts of Bolivia, southern Brazil, Paraguay, Peru and Uruguay. The earthquake was followed by hundreds of aftershocks, the strongest measuring from 6.0 to 6.9 on the moment magnitude scale. In their paper, **Bull** and **Cholaky** report on the state of SSG systems in low, medium and high-rise buildings that were inspected in the aftermath of the event.

Closure

As we publish this volume, I look forward to the next Symposium on Durability of Building and Construction Sealants and Adhesives (2014-DBCSA) and the associated flurry of papers in this dynamic industry. I encourage all readers to participate in the work of ASTM C24 committee, to attend the future symposia, and to contribute new papers. Your participation and feedback help to advance the industry and, as a result, we will all benefit from improvements to our built environment.

In closing, I would like to gratefully acknowledge the outstanding quality of the contributions made by the authors as well as the dedicated efforts of the 2011 session chairpersons, the peer reviewers, the staff of ASTM and AIP, and the Associate Editor of JAI, who all helped to make the 2011 symposium and the publication of the associated papers possible.

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Andreas T. Wolf (Editor)

A Panel Discussion: ASTM Introduces C1736 Standard Practice for Non-Destructive Evaluation of Adhesion of Installed Weatherproofing Sealant Joints Using a Rolling Device

ABSTRACT: The panel discussion was originally conceived as a discussion on sealant warranty issues, but became a spirited conversation regarding the impact of the newly developed ASTM C1736 Standard Practice with participation by the panelists, ASTM C24 members, as well as presenters and guests of the international symposium. The panel consisted of three members of ASTM C24 committee, who had direct involvement with the creation, oversight, and/or passage of C1736, plus one panelist representing a sealant applicator. In order to provide context to the discussion, the editor has provided a short introduction to the topic.

Introduction

Considerable work has focused in the past on the deterioration of building joint sealants (see, for instance, information provided in the RILEM State-of-the-Art Report [1]), while less emphasis has been placed on understanding the consequences of seal failure, particularly in respect to water-tightness. Deficiencies in the water-tightness of weather seals in building envelopes may indeed be induced by the effect of weathering on sealants, as the climatic factors may cause the sealant to deteriorate by hardening, softening (reversion), cracking, or losing adhesion to the substrate. However, deficiencies that affect the water-tightness of weather seals may also come about from design faults or improper installation. Water penetrating into the joint and into the building envelope via these deficiencies may lead to deterioration of the building fabric or premature failure of the joint sealant or of other envelope components.

By the early 2000s, a practical means of assessing adequate sealant performance in the field in terms of the quality of the sealant-to-substrate bonding following initial installation as well as during inspections carried out over the life of the sealed joint had become of considerable interest in the construction community. Since 2003, ASTM has sponsored this “Durability of Building and Construction Sealants and Adhesives (DBCSA)” Symposium Series. The need for a field practice to facilitate the inspection of sealed joints such that the continuity of the seals can readily be determined was highlighted by various presentations during this symposium series. Work presented by Lacasse, Miyauchi, and Hiemstra at the 2008 symposium demonstrated that substantial amounts of water, i.e., up to several liters per minute, can be penetrate through very small interfacial "cracks" along the bond line of the sealed joint with the crack lengths ranging between 2 mm and 16 mm [2]. Not surprisingly, water readily enters open cracks along the sealant-to-substrate interface when the joint is extended; however, the study also demonstrated that water from wind-driven rain may penetrate through cracks of non-extended (apparently "closed") joints. Loss of sealant adhesion in non-extended joints (and, even more so, in compressed joints) may not be detectable by simple visual inspection.

The most commonly used industry protocol to check joint sealant adhesion has been the destructive "pull test" procedure as described in ASTM Standard Practice C1521-09e1 for Evaluating Adhesion of Installed Weatherproofing Sealant Joints [3]. This method allows checking the adhesion of the sealant at discrete locations along the joints; however, it is not suited for the evaluation of the continuity of the seal.

In the 2003 Symposium of the DBCSA series, a method of in-field testing of sealed joints using a rolling device was presented [4]. Every symposium in the series thereafter has had one or more presentations on the topic of continuity of joint seals in terms of suitable inspection methods as well as consequences of failure. Putting words to action, in 2001, ASTM C24 Committee on Building Seals and Sealants began to look seriously at the rolling device methodology for consideration as a standard practice. Starting in 2008, work item WK21464 "Standard Practice for Non-Destructive Evaluation of Adhesion of Installed Weatherproofing Sealant Joints Using a Rolling Device" came under development by ASTM C24.30. By the time the 4th DBCSA Symposium began on June 16th, 2011, the committee had granted final approval for WK21464 just the day before, on June 15th, and subsequently gave it the designation ASTM C1736. ASTM C1736-11 Standard Practice for Non-Destructive Evaluation of Adhesion of Installed Weatherproofing Sealant Joints Using a Rolling Device has recently been published [5].

The ASTM C1736 Standard Practice describes a non-destructive evaluation procedure which induces a depression in the joint seal via a rolling device. Subjecting the sealant bead to a strain by moving the rolling device continuously over the sealed joint causes a stress on the bonding at the sealant-to-substrate interface that moves along the bond line. Controlling the amount of stress induced along the bond line allows an assessment of the quality of the adhesive bond of a joint seal in a particular installation. This practice, therefore, can be used to verify the continuity of building seals and its primary purpose is to reveal sealant adhesion anomalies that may affect air or water infiltration resistance or both of the sealed joint. It is expected that this practice will be used for quality control, forensic investigations, and repair programs. Users may include sealant manufacturers, consulting engineers and architects, test agencies, and construction contractors.

This paper is a summary of a panel discussion, originally conceived as a discussion on sealant warranty issues, but which evolved into a spirited conversation regarding the passage of C1736. The thematic thread that developed during the discussion was what impact will this standard have on the industry, in the context of historical and current industry standard practice?

The following is a summary of that discussion, with C24 members, guests, and audience participation represented generically. The panel consisted of three members of ASTM C24 committee, who had direct involvement with the creation, oversight, and/or passage of C1736, plus one panelist representing a sealant applicator. One audience member represented a Consultant in the content and total amount of comment that was offered. For clarity, additional contributory comments and questions from audience members have been woven into the responses made by the panelists. Note that names, personal comments and issues, and all otherwise off subject material have been removed.

Panel Discussion

Development of C1736

C24 Representative #1—In the mid 1990's, ASTM committee C24 decided that the industry needed a Standardized Practice to evaluate adhesion of installed weatherproofing sealants. Such a practice would have applications in new construction for quality control, existing construction for service life evaluations, and in-field "forensic" determinations of air and water infiltration sources. The result of this effort was C1521, first published in 2002 [3].

C1521 contains both destructive and non-destructive methods to evaluate sealant adhesion. The non-destructive method only looks at small areas of the sealant installation, providing a snap-shot of the total. The later added (2008 revision to C1521) 'continuous procedure using rolling devices' can be used to obtain a larger picture of the installation. However, the committee decided an additional stand-alone Standard Practice was also needed for the rolling device method. With the passage of C1736, we now have two standards for in-field evaluation of adhesion of installed weatherproofing sealants.

C24 Representative #2—The committee did a good job of writing this new standard; there were enough "controversial" points of view that a really good standard was produced. The wisdom of the ASTM process shines through in it, because if it was left up to a single individual, or a group of individuals with like thinking, it would not be as balanced as it is; it is balanced due to the diversity of thought reflected within it.

C24 Representative #3—I have come to appreciate the high level of due diligence that ASTM provides, with all of the relevant stakeholders participating in the development and review process. Sometimes we wish that the process could go a little faster, but the net result is very good standards. In addition, once a standard is published, it will be reviewed once every seven or eight years to reconcile it with changes in the industry, and if needed, the standard will be adjusted to reflect those changes.

General Implications of C1736 for the Industry

C24 Representative #2—Rolling devices are able to provide information that goes well beyond the joint appearance; sometimes joints look bad on the surface, but are good underneath, and vice versa. Joint geometry, twisted backer rod, and other anomalies can be discerned when using these devices; but, the intent of the standard is focused on adhesion. Due to the high elastic recoverability factor of many performance sealants, complete bond line failure can exist and one would never know it by looking. The intent behind the methodology of C1736 is to facilitate complete and durable building seals.

Applicator—I am skeptical regarding the ability of this test method to reveal the entire picture; there are many factors that go into a wall design, and therefore many different problems that can develop. It is my position that the best place to put extra effort is into applicator education and training – applicator certification ideally – to prevent sealant problems in the first place. I am also apprehensive regarding potential mischief that could be dredged up from such testing, costing everyone unnecessary time and money. Therefore, those using this test methodology (of C1736) should have good knowledge, expertise, and intent when using it so as to prevent misuse.

Consultant—I have been using the screen roller procedure for at least 15 years, and it is the number one tool I use because I want to know everything that is going on in that sealant joint. I place a piece of easily removable painters' type masking tape alongside the joint that I wish to analyze; I have the roller in one hand, and a felt tip pen in the other. As I roll along spot to spot in the bead, where it pushes in easily, I put a mark indicating that the sealant is very thin; when I come to a spot where the roller does not push in, I indicate on the tape that the spot is hard, heavy, or thick; when adhesion has failed, I indicate that on the tape as a line showing where the failure starts and stops. When I am finished with a specific area, I put a label on the masking tape and take a picture of it, for the record and for future analysis. This provides information that can identify systemic problems when specific issues are found to be repetitive, or share commonality. While the standard is written as a test for adhesion, much more information can be derived from its' use. A screen roller combined with a good marking and data archive system form my number one diagnostic method when conducting sealant forensic analysis. I can teach and have taught others how to use this methodology in less than an hour.

Implications of the Use of This Practice

C24 Representative #2—C1736 has two main procedures; Section 7.3 is most appropriate to in-depth analysis by an expert; Section 7.4 is more tuned to 100% evaluation for continuity of joint seal. In some cases, systemic issues are the most important thing to determine, served well by expert analysis of a discrete area. At other times it may be critical to achieve continuity of seal, meaning a 100% test and repair becomes the preferred usage of the standard. Both of these procedures have a focused purpose, and the new standard reflects the flexibility needed in the industry.

Applicator—I have a concern that this methodology could be used inappropriately to create more problems that it can resolve. For example, what is to prevent a building owner from taking his 20-year sealant warranty, commissioning a 100% analysis on the 19th year of the warranty period, and then go back to the warranty issuer with a demand for a new sealant installation? For another example, there are 20-year sealant warranties that have been written for substrates that has a 1-year warranty. How are these types of potential mischief and conflict to be resolved?

C-24 Representative #2—'What is best for the building is what is best for everyone connected to it, whether they realize it or not'. For example, two 40-foot [12.192 m] lengths of metal panel wall sections spontaneously fell from a building during a wind storm. This building was 30 years old, standing in the dry air of the Sonoran Desert in Phoenix Arizona, yet when investigated, what was found was rust rot throughout the building façade, caused by failed sealant joints leaking water for 30 years. The danger came from the fact that the seal leaks went unrecognized because the building did not leak to the inside where folks could observe it. So, for 30 years the rust rot did damage with the building owner completely unaware. We need to make sure that seal systems are truly sealed for the sake of the building first, in the interest of the public health and welfare, and then we can figure out how to pay for it. Whatever the cost, we know it will be less than the cost of a human life.

C-24 Representative #1—I agree with The Applicator that training and education for failure prevention should come first. It has been my experience that all too often the applicator/mechanic does not know why he is told to do a certain procedure. The Applicator may ignore or modify a procedure out of simple preference or ignorance, not simply as a time saving measure. I have found that when applicators fully understand the why of a certain procedure, they become very motivated to do it the right way. Why does the joint design need a certain profile; why is there a need for bond breaker tape to prevent three sided adhesion; why is primer needed on this substrate but not on that one; when Applicators understand the whys', they are most times very willing to comply with the procedural mandates. Education of field personnel to a high professional level is problem prevention; however, the fact that the testing of C1736 now exists should encourage better installation practices through better training. The two can peacefully coexist and promote each other.

C24 Representative #2—We have to remember that this is a field practice, not a laboratory test. All we are trying to do is find out whether or not we have adhesion, in a sampling or as continuity of seal in a 100% evaluation. Quantification of the results is called out in the reporting section 8 of C1736 as a ratio of failure against the total amount tested. This is written into the standard as a protection to everyone involved. For example, when properly reporting results per the standard, a hypothetical 0.5% failure rate may occur. That may mean there are enough seal breeches to warrant a full scale test and repair program, because it can mean a considerable number of potential air and water leaks in a seal grid of miles of field applied sealant; but on the other hand, it also means that the sealant was applied at and is performing at the rate of 99.5%. This is not a negative for the sealant producer or installer; it is simply the as-built degree of total continuous seal achieved within the limits of human capability. When the adhesive failures are identified, they can be repaired without replacing the entire installation. For years we have been relying on a single bead of sealant to perfectly seal buildings, when that is simply not possible in the real world of construction, unless there is an accompanying 100% test program. Now, with the methods of this new standard, we have a mechanism to test and repair those unavoidable adhesive failures, meaning we can now produce truly sealed buildings with a single sealant bead.

Applicator—I see a potential danger that a pre-existing prejudice will be label all of the problems found as "applicator error", and the whole industry will become litigious, with applicators taking the brunt of the cost and blame. I hope that the adversarial aspects of the industry can change so that we can all work together to resolve these problems without unduly placing the financial burden on applicators, sealant producers, and insurance policies.

The Future of C1736 and the Industry

C24 Representative #2—What we are hoping to achieve with the new standard is provide a venue where we can all work together to make litigation disappear, repair our infrastructure, and provide us all with better building seals that can allow structures to last longer. There is plenty of blame to go around for our collected industry past, starting with designs that require an impossible level of installation perfection. What we are trying to achieve with the new standard is provide a platform to fix buildings and move forward into the future.

C-24 Representative #1—Too often the initial installation is focused on aesthetics over function. We need to make sure buildings don't leak first, and deal with aesthetics second, although looks are also very important. Education of both designers and applicators combined with field testing can achieve both goals.

Applicator—Perhaps a maintenance programs that looks at an installations once every five years or so could become common practice. I think that would be good for owners, applicators, and the industry at large. Right now there are specifications for maintenance inspections written into construction documents, and ASTM guides such as C1193 [6] that make such recommendations, but they are not being implemented industry wide.

C24 Representative #3—Every sealant producer has to recognize that the rolling device evaluation will, from this moment forward in time, be used more and more. Producers and façade designers have a responsibility to inform the owners what these evaluations will mean in terms of repair or replacement. There are many sealant installations that are twenty or thirty years old, and there is a growing number of ordinances mandating periodic façade inspections. New and improved standards can combine with mandates and expectations to propel the industry forward into the new century. If we combine our efforts as an industry, we can bring building seals into an unprecedented age of function and durability we once only dreamed about.

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