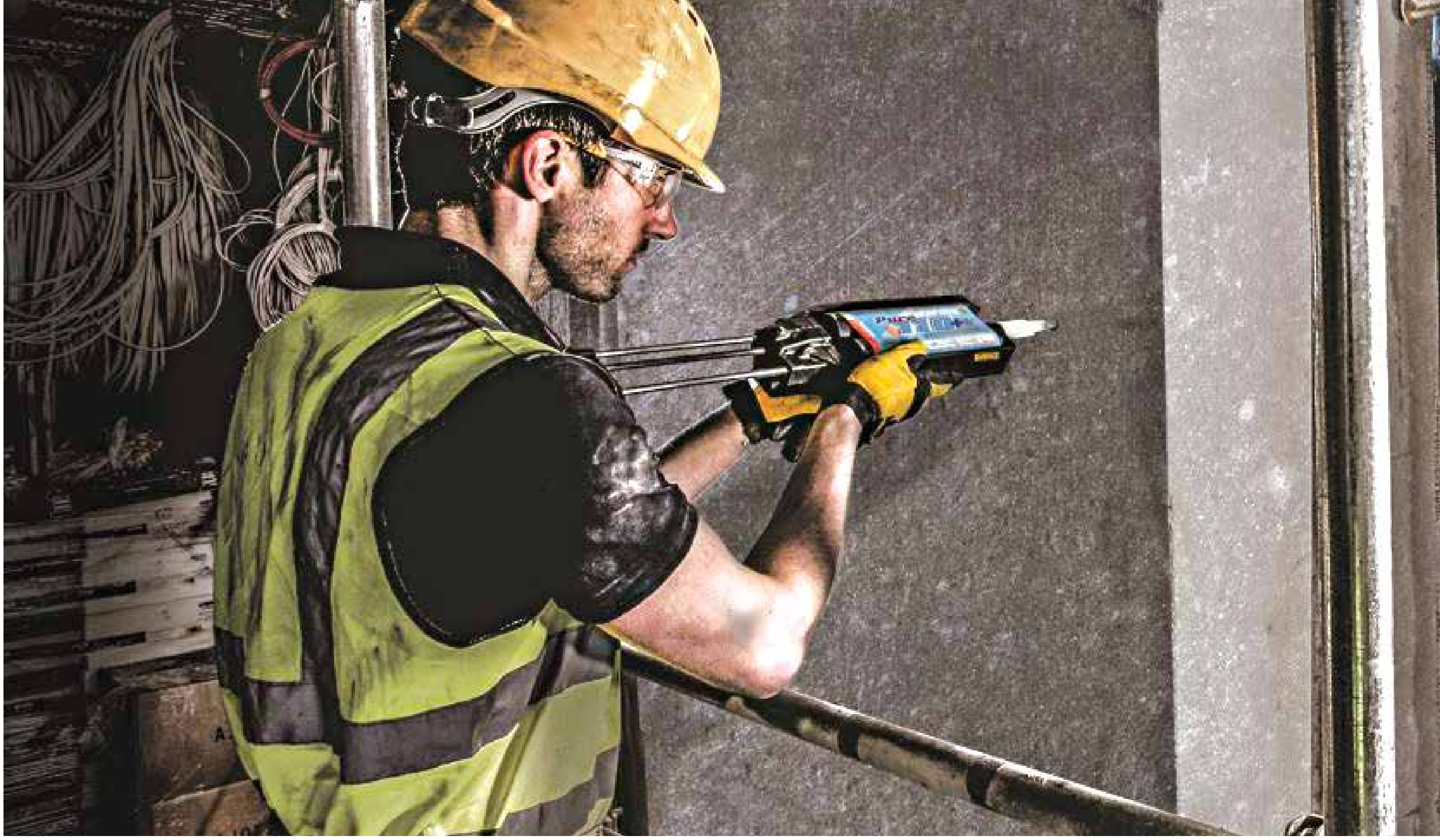

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The Effects of Temperature on Post-installed Adhesive Anchors

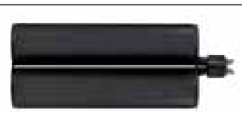
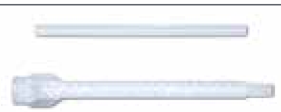
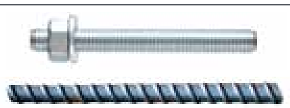
Andra Hoermann-Gast and Jacob Olsen

Background of temperature effects on adhesive anchors

Post-installed adhesive anchors are frequently used in the construction industry for connections to concrete and masonry structures. They are used as alternatives to other types of post-installed anchors like expansion anchors, undercut anchors or screw anchors. For the case of adding rebar to hardened concrete, known as post-installed rebar, adhesive anchor systems are typically the only option to make this connection.

Adhesives used for anchoring typically take the form of either a two-part resin and hardener (e.g., epoxy) or a two-part resin and catalyst (e.g. acrylate) that can be packaged in cartridges, glass tubes, foil packages or delivered in semi-bulk containers. There are two primary types of anchoring adhesives: epoxy resin systems and radical-cured systems which include vinylesters, acrylates and polyester resins. When the two parts are mixed together in the correct proportion, they chemically react to form a durable polymer matrix which, when used with a threaded rod or reinforcing bar, can create a robust concrete anchor. In addition to the adhesive and steel anchor element, a complete adhesive anchor system will also include a variety of hole cleaning and installation tools as required in the manufacturer's published installation instructions. Typical items are shown below.

Table 1: Components of an Adhesive Anchor System

			
Adhesive Cartridge	**Dispensing Tool**	**Mixing Nozzle and Extension**	**Steel Element**
			
Piston Plug	**Rotary Hammer Drill**	**Clearing Brush and Air Wand**	**Carbide Tipped Drill Bit**

Adhesive anchors became directly referenced in the International Building Code (IBC) for the first time with the ACI 318-11[1] standard which is the design basis for the IBC 2012[2]. In 2010, ACI Committee 355 published a standard that addresses the qualification of adhesive anchor systems for use with the ACI 318-11 Appendix D anchor design provisions. This 355.4[3] standard was drafted on the basis of the ICC-ES AC308 provisions that had been in use since 2006, but with some significant modifications, particularly with regard to temperature considerations. The following test series in AC308[4] are temperature-relevant:

- Sensitivity to freezing / thawing conditions
- Sensitivity to sustained load
- Tension at elevated temperatures
- Tension at decreased installation temperature
- Overhead and horizontal installation at elevated and decreased temperature
- Curing time

Whereby ACI 355.4 generally adopts the temperature-relevant tests without modification, the available temperature ranges for qualification of the adhesive anchor system (both short- and long-term maximum permissible elevated temperatures) are significantly altered. Under the rules established by ACI 355.4, it is no longer permissible to publish bond stresses suitable only for "room temperature" applications. The minimum long-term temperature for which the system must be qualified is 110°F (43°C). The most recent version of AC308 further expands the required temperature testing in ACI 355.4 to include cure time tests at both the minimum and maximum temperature for which the system is recognized (not just for room, or standard temperature conditions), and adds a new test for products to be recognized for applications (e.g., façade anchorage) in which temperatures can vary rapidly over a 12-hour period.

When handled, designed, and installed correctly, post-installed adhesive anchors are an excellent solution for many concrete anchoring applications. As with all organic adhesives, adhesive anchors are sensitive to temperature. To ensure a sound connection the effects of temperature on adhesive systems must be considered before, during and after installation.

The main temperature influences can be divided into three groups:

1. *Storage temperature of the adhesive, which can influence the shelf life*
2. *Temperature of concrete and adhesive at the time of installation, whereby both low and high temperatures are relevant for the gel, cure time, and adhesive viscosity.*
3. *Temperature of the concrete over the service life of the anchorage. Elevated temperatures can markedly affect the bond strength.*

Storage temperature of the adhesive (shelf life)

The typical shelf life of adhesive anchor systems is about 12-24 months when stored under a typical temperature range of about 40°F to 77°F (4°C to 25°C). The specific long-term storage temperature as well as the short-term temperature exposure limits of the adhesive prior to installation are given in the ICC-ES Evaluation Reports (ESRs) and are also provided in the Manufacture's Published Installation Instructions (MPII). Adhering to these limits is critical to ensure that there is no degradation of the adhesive prior to installation. Note that special consideration may be required for adhesive anchors that are stored on jobsites for extended periods. High temperatures can occur in typical jobsite lock boxes exposed to the sun and can cause liquid separation and permanent degradation of key ingredients. Likewise, products that are not protected from freezing temperature conditions can experience crystallization which can significantly reduce the strength of the anchor.

Installation temperature of concrete and adhesive, both low and high temperatures (gel and cure time)

During installation, two critical parameters known as the gel time and the cure time are both directly dependent on temperature. The gel time of an adhesive is the working time during which the adhesive can move or be worked without any negative impact on the strength of the anchor. The gel time starts when the two parts of the adhesive begin mixing together which initiates the chemical reaction. In the case of static mixing nozzle systems this curing starts in the nozzle, and therefore the gel time also applies to the adhesive in the nozzle. The mixing nozzle must be replaced with a new nozzle when adhesive in the nozzle has exceeded the gel time. After the gel time has elapsed, the adhesive (including the steel anchor element) must remain undisturbed until the full cure time is achieved.

The cure time of the adhesive is the amount of time required, after mixing, to achieve the full strength of the adhesive. Loads should not be applied to the anchor until the cure time is reached.

Each adhesive anchor system will have both a unique gel time and cure time that is dependent on the temperature of the concrete during the installation. This should not be confused with the air temperature. For example, a large mass of concrete that has been exposed to cold temperatures at night will warm up much more slowly than the air around it. The gel and cure time information can be found on both the adhesive packing and in the ESR. A typical gel and cure time table is shown below.

Table 1: Example Gel and Cure Time Table

Temperature of the concrete	Gel (working) time	Full curing time
41°F (5°C)	180 minutes	50 hours
50°F (10°C)	120 minutes	30 hours
68°F (20°C)	30 minutes	10 hours
86°F (30°C)	20 minutes	6 hours
104°F (40°C)	12 minutes	4 hours

The low end of the temperature range represents the minimum base-material temperature at which the adhesive can be installed, 41°F (5°C) in this example table. Some types of adhesives will not cure below a minimum temperature so this is important to verify during installation. A second more practical issue with low temperature installations is the dispensability or pump-ability of the adhesive at low temperatures. Many types of adhesives will become difficult to dispense (increased viscosity) as the temperature decreases. A typical solution for this problem is to warm the adhesive prior to use which can help the adhesive flow easier. While this is acceptable for many products, it should not be assumed this applies to all adhesive anchor systems and the ESR, the product literature or manufacturer should be consulted prior to warming the adhesive. Furthermore, the minimum concrete temperature must still be observed, regardless of the adhesive temperature.

The upper end of the temperature range represents the highest concrete temperature that the adhesive can be installed in, 104°F (40°C) in this example table. Higher temperatures result in both decreased gel times and cure times. Often, the high end of the temperature range is limited by the practical working time (gel time) needed to properly install an adhesive anchor as increased temperatures can considerably shorten the gel time. Some products can have a gel time as short as 60 seconds in warm temperature conditions. For the case of anchors with a deep embedment depth, the time required to inject the adhesive and properly install and position the steel element can be significant. For these reasons, the benefits of using a quick-curing adhesive must be weighed against the possible risk that the gel time will be insufficient for proper installation. Additionally, the adhesive viscosity at higher temperature is typically reduced, which can result in the adhesive running out of the hole in horizontal and overhead installations if additional precautions are not taken.

Service temperature, both low and high temperatures

After an adhesive anchor has been properly installed and cured, temperature continues to have an impact on the anchorage. For this reason, the anticipated temperature the adhesive anchor experiences during the service life of the building or structure it is installed in must also be taken into account during the product selection and design of the adhesive anchor. There are 3 primary service temperature concerns that must be considered: minimum service temperature, maximum service temperature, and potential fire exposure. In all cases, the temperature refers to the interior temperature of the concrete in the vicinity of the anchor, again, not to be confused with the air temperature.

Minimum Service Temperature

All adhesive anchor systems assessed under AC308/ACI 355.4 must pass a freezing and thawing test to ensure performance in cold-weather environments. Although the ESRs do not explicitly state a minimum service temperature, the ACI 355.4 standard recognizes the use of adhesive anchors in concrete that may experience in-service temperatures as lows as -40°F (-40°C). This lower limit is based on current experience with common types of adhesive systems and does not necessarily indicate that there will be problems with adhesive anchors at even lower temperatures, however the adhesive anchor manufacturer should be consulted for these conditions.

Maximum Service Temperature

Correct determination of the maximum expected service long term and short term temperature is one of the most important factors during adhesive anchor design, and also one of the most difficult responsibilities of the designer considering unanticipated changes during the service life of a structure and unknown service conditions throughout the building. For example, a building may be repurposed, or closed for extended periods with no operable ventilation or air-conditioning systems. Likewise, anchors near the south-face of the building which experiences daily sunlight can have a significantly different temperature exposure than those in a protected lower floor or sub-grade location, despite the anchors being used for the same application.

ACI 355.4 defines long term and short term temperature as follows:

Elevated concrete temperatures arise from a number of factors, including sun exposure, proximity to operating machinery, or containment of liquids or gasses at elevated temperature. To establish design bond strengths, two classes of elevated concrete temperature are identified:

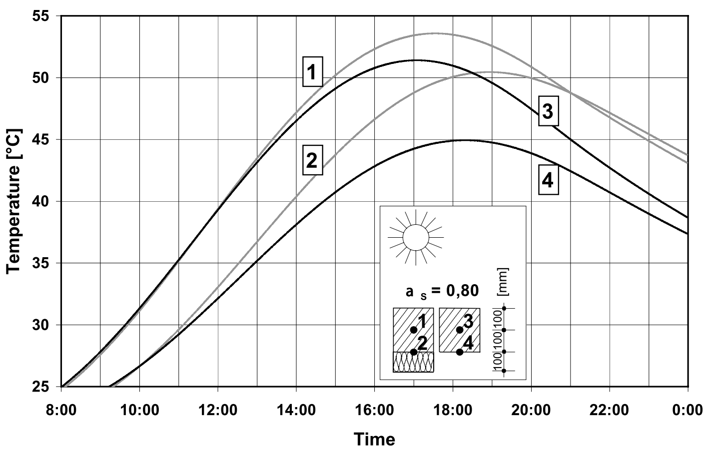
1. *Where elevated concrete temperatures are transient or part of a regular cycle of heating and cooling, such as day-night temperature rise and fall, they are considered short-term elevated temperatures for the purposes of this standard;*

   and

2. *Where concrete temperatures may remain elevated over weeks or months, they should be considered long-term elevated temperatures.*

While the temperature for some anchors in a structure can be relatively constant such as anchors into concrete below grade in contact with the earth, many anchors will experience some type of daily or weekly temperature cycles due to both the sun as well as typical HVAC heating and cooling schedules. For example, many commercial buildings will suspend temperature regulation on Saturday and Sunday for energy conservation purposes. While it is understood from the definition above that the peak temperatures reached during these cycles should be treated as short-term elevated temperatures, for these anchors exposed to regular cyclical temperatures – it is not clear on how to select the proper long term temperature. Figure 1 below comes from a research paper[5] on this topic and depicts daily temperature cycles for a 200 mm (8") concrete slab exposed to the sun in Berlin (Central Europe). As can be seen, the peak or short-term temperatures are in excess of 50°C (>120°F) at a depth of 100 mm (4"), but it should also be noted that the temperature at this depth remains above 40°C (104°F) for more than 10 hours each day. The appropriate long term temperature for this type of cycling could be estimated as an average of the temperature cycle for these conditions, and would be at least 35°C (95°F) to 40°C (104°F).

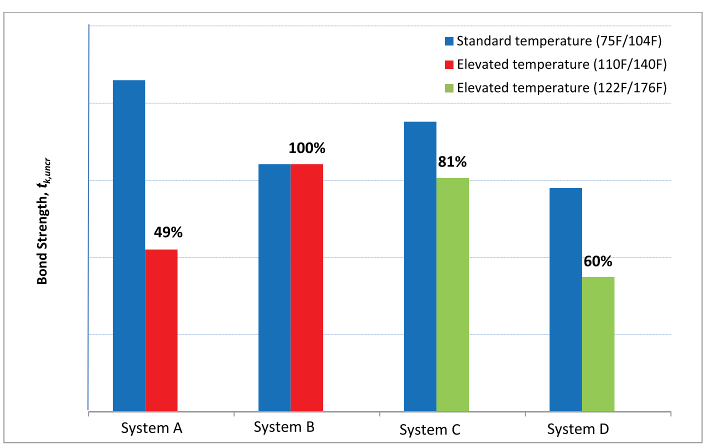
Figure 2: Daily temperature cycles for anchors in a concrete slab exposed to the sun



Due to both the significant influence of temperature on the bond strength of adhesive anchors, and the difficulty both to predict and define an appropriate long term temperature for many applications, ACI 355.4 requires all anchors to be designed at a minimum of 110°F (43°C) long-term temperature, and 130°F (54°C) short term temperature. Prior to ACI355.4, adhesives were permitted to be designed with a long-term temperature of 66°F (19°C) (equivalent to room temperature). This new requirement creates a significant limitation on the design capacity for some products that, due to the underlying chemistry of the product, are very sensitive to even modest increases in temperature that would be expected during service conditions.

Figure 3 shows a comparison of the characteristic bond strength of four adhesive anchor systems that have been evaluated by ICC-ES. For each product, the bond strength values at a standard temperature range and an elevated temperature range in uncracked dry concrete are shown. As can been seen, the temperature effect varies significantly with some products having little or no reduction in bond strength at elevated temperature.

Figure 3: Comparison of the Characteristic Bond Strength for Various Adhesive Products



Fire Exposure

Perhaps the most severe temperature condition that an adhesive anchor may experience during the service life is direct exposure to a fire. In general, ACI 318 does not address fire, and ICC-ES ESRs for adhesive anchor systems are also silent on this subject owing to a lack of consensus on the manner in which data should be developed and used in design. Research on this topic, particularly for the case of post-installed reinforcing bars, is currently being pursued. In Europe, procedures for qualification of anchor systems for various fire resistance classes (30-, 60-, 90-minutes, etc.) have been developed by EOTA and published as TR020[6]. Testing usually consists of installation of the anchor in a concrete slab that serves as the lid of the burn chamber. The anchor is then loaded with hanging weights and the burn chamber is run according to a standard time-temperature curve, whereby the time to failure of the anchor is recorded. This test simulates anchors directly exposed to fire; however, in many cases where structural connections are made with anchors, the anchors are protected in a similar manner as structural steel components. For systems used to secure nonstructural components, e.g., above the ceiling, fire protection requirements are generally not imposed on the individual parts, e.g., hanger rods, clevises, trapezes, etc., and as such no requirements are placed on the anchors.

Summary

Post-installed adhesive anchors have become an integral part of the designer and contractor's tool box providing a reliable means for anchoring to concrete. Their versatility makes them an attractive solution for many common applications. In order to ensure a reliable connection, adhesive anchors must be handled, installed and designed properly, and the effects of temperature must be considered during all three of these phases.

About the Authors

Andra Hoermann-Gast is a staff engineer with ICC Evaluation Service, LLC. Prior to joining ICC-ES in 2008, Andra worked for several years at the Deutsches Institut für Bautechnik (DIBt) in Berlin. She is actively involved in the development of anchor-related ICC-ES acceptance criteria and evaluation reports.

Jacob Olsen, PE is a civil engineer with 15 years of experience in the concrete anchoring industry including independent testing, product development, codes and standards development and anchorage design. He is currently the Vice President of Global Field Engineering at Powers Fasteners.

ICC EVALUATION SERVICE

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[2] International Code Council (June 2011), *2012 International Building Code (2012 IBC).*

[3] American Concrete Institute (2011), *Qualification of Post-Installed Adhesive Anchors in Concrete (ACI 355.4) and Commentary.*

[4] International Code Council Evaluation Services (September 2014), *Acceptance Criteria for Post-installed Adhesive Anchors in Concrete Elements (AC308).*

[5] Universität Stuttgart, Institut für Werkstoffe im Bauwesen (IWB), Thorsten Hüer, Werner Fuchs (2001), *Temperature Distribution in Concrete Members due to Solar Radiation, Report No.: 01/16-2/42*

[6] European Organisation for Technical Approvals (EOTA), Technical Report TR020 (2004), Evaluation of Anchorages in Concrete concerning Resistance to Fire