Latest developments in adhesive anchoring technology

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Abstract. Adhesive anchoring is used to connect steel and concrete elements and to connect new to existing reinforced concrete structures. For this, threaded rods or reinforcing bars are bonded to the hardened concrete by adhesives. Internationally recognized qualification guidelines and design codes form the regulatory basis for all approved products and ensures a high level of safety. This paper introduces the context of adhesive anchoring systems. An overview of relevant international regulations is provided, and the difference between post-installed anchor and post-installed rebar applications is explained. The latest developments in adhesive anchoring in regard to qualification and design is presented. The contribution aims at bringing the adhesive anchoring technology to the attention of a broader audience of the engineering and research community.

1. Introduction

Post-installed adhesive anchoring systems consist of a steel element and an adhesive to bond the steel element to the concrete base material (Fig. 1a). The steel element is in general a threaded rod or a reinforcing bar (Fig. 1b). Post-installed adhesive anchors are used to connect structural and nonstructural elements to the existing concrete structure. Post-installed rebars (PIRs) may also be used for connecting new concrete to existing concrete, allowing economic construction methods (Fig. 1c).

Figure. 1 a) Cartridge and mixing nozzle; b) Threaded rod and reinforcing bar; c) Starter bars installed with Dewalt PE1000+ adhesive at the M32 Highway improvement project, Taoyuan county, Taiwan
The adhesives used for anchoring in concrete are two-component systems. Due to their superior performance and slow-setting properties required in warm climates, many adhesive systems are epoxy type consisting of resin and hardener. Further adhesive systems base on epoxyacrylate, vinylester, polyester, or hybrids with some cement content; all of which fast-setting. First applications of adhesive in construction reach back half a century when bulk ware was used to mix the components on site. The commercial breakthrough of adhesive anchoring was finally experienced when cartridges allowed the injection of the exact adhesive quantity required directly into the hole drilled for installation. For this, the chemical components are filled in the compartments of the cartridges and balanced when they are dispensed through the mixing nozzle. Further information also regarding required accessories can be found in [1].

2. Background
During past fifteen years, substantial research and development have been made to increase the fields of applications and the safety of anchors and PIRs. Frequently updated qualification and design regulations reflect the latest state-of-the-art in the US and Europe. Third party testing makes approved anchoring systems very trustworthy.

2.1. Consistent system of qualification, approval and design
Third party approval documents provide design data for the conditions the anchor has been qualified for. Approved products guarantee a high level of safety due to the closed system of qualification, approval and design (Fig. 2). The qualification and design requirements in the US and Europe are largely harmonized [2]. Worldwide, designers and specifiers show an increased awareness for approved products and their benefits in view of safety and performance.

![Figure. 2 Safety by qualification guidelines, technical approvals, and design guidelines (after [3])](image)

2.2. Adhesive anchors and post-installed rebars
Engineers and designers are sometimes confused by the difference of anchor applications and PIR applications. While threaded rods are always designed as adhesive anchors, reinforcing bars can either be designed as adhesive anchors or as PIRs [4]. Adhesive anchors are designed according to anchor design rules. They typically require large edge distances due to the high bond strength they are designed for. PIRs are designed similar to cast-in reinforcing bars for development length. Since structural concrete design codes limit the maximum bond strength to relatively low values when developing the rebar, PIRs typically require deeper embedments. Because of the different underlying design assumptions, the qualification programs of adhesive anchoring systems differ for PIR and anchor applications. An overview of the relevant regulations is provided in Table 1.
3. Latest developments

Technical approvals of construction products like the ETA and ESR (ICC-ES) certify the performance data for the intended use of the product and an assumed service life of 50 years. For adhesive anchoring systems, performance data are primarily load capacities for the approved size range (e.g. M8 to M30 and 3/8” to 1-1/4” threaded rods, and Ø8 to Ø32 and #3 to #10 reinforcing bars), minimum and maximum embedment, as well as required edge distance and spacing. The minimum test program for adhesive anchoring systems already requires many different tests ([5], [6], [7]), including i.a. installation tests, pullout tests and creep tests at various temperatures, freeze-thaw tests, repeated load tests, tests for sensitivity to reduced cleaning effort, corrosion tests, and tests for sensitivity to sulphurous atmosphere and high alkalinity. Further tests allow the qualification for additional design applications.

3.1. 100 year design

While structural design codes generally assume a service life of 50 years, civil structures like bridges are sometimes designed for 100 years. For this kind of application, adhesive anchors can now be qualified for 100 year design according to the EAD 332077 [11]. For this, extra third party tests are required in addition to the basic qualification program stipulated in EAD 330499 [5]. To represent the doubled service life, critical tests are conducted with doubled test parameter. These are namely: (i) Repeated load tests where the anchor is subjected to 200,000 load cycles instead of 100,000 load cycles. A description of this test type can be found in [2]. (ii) Crack movement tests where the crack, the tested anchor is installed in, is cyclically opened and closed 2000 times instead of 1000 times. A description of this test type can be found in [12]. (iii) Sustained load tests (Fig. 3) running 6 months instead of 3 months.

![Figure 3](image_url)

**Figure. 3** a) Sustained load test setup [13]; b) Example creep curve (measured displacement over time) and Findley projection for an example anchor [14]

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### Table 1. Regulations for qualification and design of PIRs in Europe and the USA

| Qualification guideline | Europe | USA |
|-------------------------|--------|-----|
| Anchor application      | EAD 330499 [5] | ACI 355.4 [7] |
| PIR application         | EAD 330087 [6] | ACI 355.4 [7] |
| Technical approval      | ETA    | ESR (ICC-ES) |
| Design code             | EN 1992-4 [8] | ACI 318 [10] |
|                         | EN 1992-1-1 [9] | Chapter 17 |
|                         |        | Chapter 25 |
Sustained load tests are critical for the evaluation of the load and creep performance of adhesive anchors, and for the determination of the characteristic bond strength to design with. They are conducted in normal ambient temperature as well as in maximum long term temperature. For this, the installed anchor is loaded over the required test duration (Fig. 3a), and the measured displacement is extrapolated using the Findley projection (Fig. 3b) and compared against reference values.

3.2. Seismic C2 qualification
Seismic loads are one of the most severe but least predictable actions structures and attached components may be subjected to. Seismic qualification of anchors has been covered in the US for long time but only recently introduced in Europe as a 2-tiered qualification requirement within the EAD 330499 guideline [15]. The qualification for a higher seismicity or higher risk category (akin to building importance) is denominated C2. The superior performance of C2 anchors is not expressed by better design parameters, such as increased design strength and decreased design displacement, but rather verified by a more rigorous test regime accounting for more adverse test conditions. To qualify for C2, anchors have to pass successfully simulated seismic tests with extreme cyclic anchor load and crack width regimes (Fig. 4a). To further increase safety, the introduction of C2 qualification requirements for ICC-ES approvals is currently debated in the US [16].

The other way around, seismic qualification of PIRs has been feasible for ICC-ES approvals according to ACI 355.4 for quite some time, but for ETA only with the publication of the EAD 331522 [17]. For this, PIRs are subjected to seismic loading and their performance compared to that of cast-in reinforcing bars. (Fig. 4b). Further, the minimum concrete cover can be determined by splitting tests.

3.3. Fire rating
Fire catastrophes are frequently recurring events with fatal consequences in particular for high-rise buildings. Fire ratings of critical building components are important for passive fire safety. The fire performance is evaluated for specific fire durations, typically ranging from 30 to 120 minutes (F30 to F120). In case of adhesive anchors, the duration till anchor failure is determined by fire tests according to EOTA TR 020 [18]. For this, several anchors are installed overhead in a concrete slab and loaded by dead weights while burned fuel heats the furnace according to the standard temperature curve (Fig. 5a). The fire design strength is provided in a fire report. For fire rating of PIRs according to EAD 330087 [6], reinforcing bars are installed in a concrete cylinder that is heated by an electrical furnace, and hydraulically loaded to failure (Fig. 5b). Test series at variable temperatures result in a bond reduction curve published in the ETA. This curve is then taken as input parameter for FE simulations of specific design situations and fire durations. The determined fire design strength is again provided in a fire report.
Figure 5 a) Fire test on anchors (example picture taken from fire report on Dewalt Pure110 adhesive [19]); b) Fire test on PIRs (example picture taken from fire report on Dewalt PE1000 adhesive [20])

Fire qualification of bonded anchors and PIRs is complex [21] and subject of ongoing research. Fire performance of adhesives are progressively improved and high performing adhesives are now qualified for up to 240 minutes fire (F240) in PIR applications. Due to missing regulations in the US, US design professionals fall back on the European fire reports.

4. Conclusion
Adhesive systems allow state-of-the-art anchoring in concrete with unprecedented flexibility. The consistent system of qualification guidelines, technical approvals, and design codes ensures a safe connection between steel and concrete (anchor), and concrete and concrete (PIR). US and European regulations are most advanced and to a great extent harmonized. Because of their extreme testing requirements US and European regulations are internationally recognized; and third party testing makes products approved by an ETA or ESR very trustworthy (Fig. 6).

Figure 6 Technical approval documents: Front pages of a) ETA and b) ESR (ICC-ES)

Products and regulations are permanently advancing. The latest product generation are high performing epoxies that are approved beyond regular applications of anchors and as PIRs. Recent code developments allow to expand the design service life from 50 to 100 years based on extended testing. New seismic requirements have been introduced to qualify anchors for the performance category C2, and PIRs for seismic applications. Fire tests on anchors and PIRs provide ratings for up to 240 min fire durations. – Approved adhesive anchoring systems are surely tested to extremes.
Opinions, conclusions, and recommendations expressed in this paper are those of the authors only and do not necessarily reflect those of the authors' affiliations or other sponsoring agencies.

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