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ICC Evaluation Service, LLC
Western Regional Office
3060 Saturn Street, Suite 100
Brea, CA 92821
tel: 562.699.0543
fax: 562.695.4694
www.icc-es.org

Clarification regarding the application of the β term in AC308 Eq. (10-12):

During the October 2014 ACI Committee 355 meeting in Washington D.C. a question was raised regarding the application of the terms α_{lt} and α_{st} in Eq. (10-12) of ACI 355.4-11[1] . Specifically, it was noted that these terms are evaluated using the results of tests that also provide values for the evaluation of β. In the ensuing discussion doubts were raised as to whether the reductions resulting from long-term and short-term load temperature influence are applied twice (double-counted) in Eq. (10-12). This is however not the case as will be shown in the following. The relevant sections are taken from ACI 355.4-11 and are unmodified in AC308[2]:

Eq. (10-12) includes β, α_{lt} and α_{st} as follows:

$$\tau_{k(cr,uncr)} = \tau_{k,nom(cr,uncr)}\, \beta\, \alpha_{lt}\, \alpha_{st}\, \alpha_{dur}\, \alpha_{\rho}\, \alpha_{conc}\, \alpha_{cov}\, \alpha_{cat3} \quad \text{psi} \qquad (10\text{-}12)$$

The terms relevant for this discussion are defined as follows:

β = $\min[\min(\alpha/\alpha_{req});\ \min \alpha_{adh}]$ for the reliability and service-condition tests listed in Tables 10.3 and 10.4; α is the ratio of reliability test result to reference test result evaluated for all reliability tests listed in Table 10.3 (refer to Eq. (10-17)); α_{adh} is the reduction factor for loss of adhesion as evaluated for all reliability tests listed in Table 10.3 and for all service-condition tests listed in Table 10.4 (10.4.4.2);

α_{lt} = reduction factor for maximum long-term temperature (refer to Eq. (10-26));

α_{st} = reduction factor for maximum short-term temperature (refer to Eq. (10-27));

The terms α_{lt} and α_{st} are evaluated in accordance with Sections 10.13.1 and 10.13.2 as follows:

10.13.1 Calculate α_{lt} from the tension test results at the long-term test temperature using Eq. (10-26).

$$\alpha_{lt} = \min\left[\frac{\bar{N}_{lt}}{\bar{N}_0}; \frac{N_{k,lt}}{N_{k,0}}\right] \le 1.0 \qquad (10\text{-}26)$$

10.13.2 Calculate α_{st} from the tension test results at the long-term test temperature using Eq. (10-27).

$$\alpha_{st} = \min\left[\frac{\bar{N}_{st}}{0.8\bar{N}_{lt}}; \frac{N_{k,st}}{0.8N_{k,lt}}\right] \le 1.0 \qquad (10\text{-}27)$$

In Eq. (10-26), the terms $\bar{N}_0$ and $N_{k,0}$ represent the mean and 5% fractile results of tension tests at standard temperature (essentially room temperature).

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Finally, the tests relevant for the determination of β are given in Tables 10.3 and 10.4 as follows:

Table 10.3 – Reliability tests relevant for determination of min(α/α_{req}) and min α_{adh} in Eq. (10-12)

Table 3.1			**Table 3.2**						**Table 3.3**			
Test no.			**Test no.**						**Test no.**			
3	4	5*	3	4	5	6	**7**	8*	3	4	5	6*

*Optional tests.

Table 10.4 – Service-condition tests relevant for determination of min(α/α_{req}) and min α_{adh} in Eq. (10-12)

Table 3.1					**Table 3.2**								**Table 3.3**				
Test no.					**Test no.**								**Test no.**				
7a	7b	8a	8b*	8c	11a	11b	11c	11d	**12a**	12b*	12c	17	8a	8b	9a	9b*	9c

*Optional tests.

To understand the correct determination of the temperature reduction, the following example is instructive:

For a test program conducted in accordance with Table 3.2, Test no. 7 (shaded in Table 10.3 above) is the tests for sensitivity to sustained loads, which is used to determine the reliability of the adhesive anchor system under sustained tension loading at standard and at elevated temperatures. Test no. 12a (shaded in Table 10.4 above) comprises tension tests at elevated temperature (short- and long-term), used to establish the sensitivity of the bond to elevated temperature under short-term loading. The results of Test no. 12a are used to calculate α_{lt} and α_{st} in accordance with Eq. (10-26) and (10-27), respectively. Since test series 12a is also listed in Table 10.4, one could conclude that the results are also used for the determination of β. To illustrate why this is not the case, we shall assume the following values are determined from the test program:

α_{lt} = 0.65

α_{st} = 0.80

Result of Test no. 7 residual tension capacity = 80% of the reference value (e.g., α/α_{req} =0.8/0.9 = 0.89)

Note that, whereby the value of $\min \alpha_{adh}$ is evaluated for all tests in Tables 10.3 and 10.4, the ratio of α/α_{req} is only applicable to those tests for which a value of α_{req} is defined, see section 10.4.3.1:

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10.4.3.1 For those reliability tests listed in Tables 3.1, 3.2, or 3.3 for which α_{req} is defined, calculate the value of α using Eq. (10-7) and the results of reference tension tests conducted in the same test member or concrete batch with anchors having the same diameter.

$$\alpha = \min\left[\frac{\overline{\tau}_{u,i}}{\overline{\tau}_{o,i}}; \frac{\tau_{k,i}}{\tau_{k,o,i}}\right] \qquad (10\text{-}7)$$

Test no. 7 is associated with a value of α_{req} = 0.90 (see Table 3.2). That is, the residual capacity of the anchor after sustained loading must achieve at least 90% of the short-term tension strength. Note, however, that Test no. 12a is not associated with a value for α_{req} in Table 3.2. Therefore, the results of Test no. 12a are only used for the determination of $\min\alpha_{adh}$ in accordance with sections 10.4.4.5 and 10.4.4.6.

So, for our example, let's assume these values are determined as follows:

Test no. 12a short-term elevated temperature min α_{adh} = 0.9.

Test no. 12a long-term elevated temperature min α_{adh} = 1.0.

Therefore, for the determination of the design bond stress, considering only the temperature effect, we have:

β = min (0.89, 0.9, 1.0) = 0.89

$$\tau_{k(cr,uncr)} = \tau_{k,nom(cr,uncr)} \times 0.89 \times 0.80 \times 0.65 \times \alpha_{dur}\ \alpha_{\rho}\ \alpha_{conc}\ \alpha_{cov}\ \alpha_{cat3} \qquad (10\text{-}12)$$

Summary: The results of the elevated temperature tests directly influence the design bond strength via the temperature-related terms α_{lt} and α_{st} in Eq. (10-12). The effects of elevated temperature are also reflected in the determination of β but only insofar as they affect long-term strength (i.e., "creep effects" as determined from the residual strength in test series 7) and the load at which loss of adhesion occurs. Thus, the terms α_{lt} and α_{st} are not "double-counted" in Eq. (10-12).

For more information, contact Andra Hoermann-Gast at ahoermann-gast@icc-es.org

[1] American Concrete Institute (2011), *Qualification of Post-Installed Adhesive Anchors in Concrete (ACI 355.4) and Commentary*.
[2] ICC-ES (September 2014), *Acceptance Criteria for Post-installed Adhesive Anchors in Concrete Elements (AC308).*