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To cite this article: Jan Barnat *et al* 2019 *IOP Conf. Ser.: Mater. Sci. Eng.* **471** 052020

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To the Problems of Anchoring Adhesives in High Performance Concrete

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Abstract. The paper deals with selected problems of special use of bonded anchors. It is focused closely on the limits of some epoxy and vinyl ester resins for use as anchoring adhesive in high strength concrete. If the anchor is loaded by tension force in such conditions, the adhesive may be the weakest material in the anchoring system. Therefore, it is necessary to study and describe which parameter is mostly influencing the final resistance of the anchor. The first part of the contribution discusses the design approaches used in codes for the bond failure type. The influence of concrete and adhesive performance is closely described in related references. In the main part of the analysis, experiments with epoxy and vinyl ester adhesives suitable for anchoring in high strength concrete are presented. The analysis is closely focused on bond strength experiments using the steel specimens. The effect of concrete influence is excluded in this case. Several mixtures of high performance epoxy resin and vinyl ester resin are presented. Some tests of resin filled by milled limestone and milled recycled FRP reinforcement are also included. The problem of the testing epoxy adhesive strength itself is also one of the aims of the analysis. The thickness of the adhesive layer is very small in such applications, therefore, it is quite complicated to find appropriate test configuration and also the shape of test specimen. Results of experiments in concrete specimens have shown that the shear strength of the adhesive is the crucial parameter under such conditions. Therefore, the new steel specimen, which is effective for the testing of this shear strength, was designed. The design of this specimen is presented in this paper. The results of this analysis show that the limiting value of the shear strength of such adhesives is close to 30 MPa. In addition, some problems of adhesive shrinkage during the hardening time appeared in tests and they are presented in load-deformation diagrams. The progress and configuration of the experiments as well as the results are described in this paper.

1. Introduction

The base line of the topic of this paper is the bonded anchor loaded by tension force. This basic problem of structural anchoring has been analysed in many research papers in past years. Therefore, the real behaviour of bonded anchor under tension load is described very well. On the other side, in some special conditions and uncommon situations there are still many problems to solve.

One of the remaining problems is the influence of adhesive strength to the tension resistance of the anchor. When the anchor is installed in concrete, which has high values of strength, the adhesive is the weakest point in the anchoring system. The anchor resistance is in such case defined according to the ETAG or EC [1, 2] standards by the value of bond strength. Bond strength is an overall parameter of the connection quality between anchor bolt and concrete. It can be obtained by the confined test [1].



It can be presumed that the bond strength is determined mainly by the characteristics of the adhesive in case when the difference between concrete and adhesive strengths is high. When the concrete strength is very high, the effect of its strength to the final bond strength is negligible. This is one of the reasons why it is important to test the characteristic of the adhesive itself. Such kind of test is not defined by codes related to the anchoring.

2. Experiment configuration

For the evaluation of adhesive strength, we decided to use the same principle of confined test according to [1]. The basic concrete specimen was substituted by a steel specimen. The roughness of the outer contact of the adhesive is provided by female thread in the opening. The scheme of the steel specimen is displayed in figure 1.

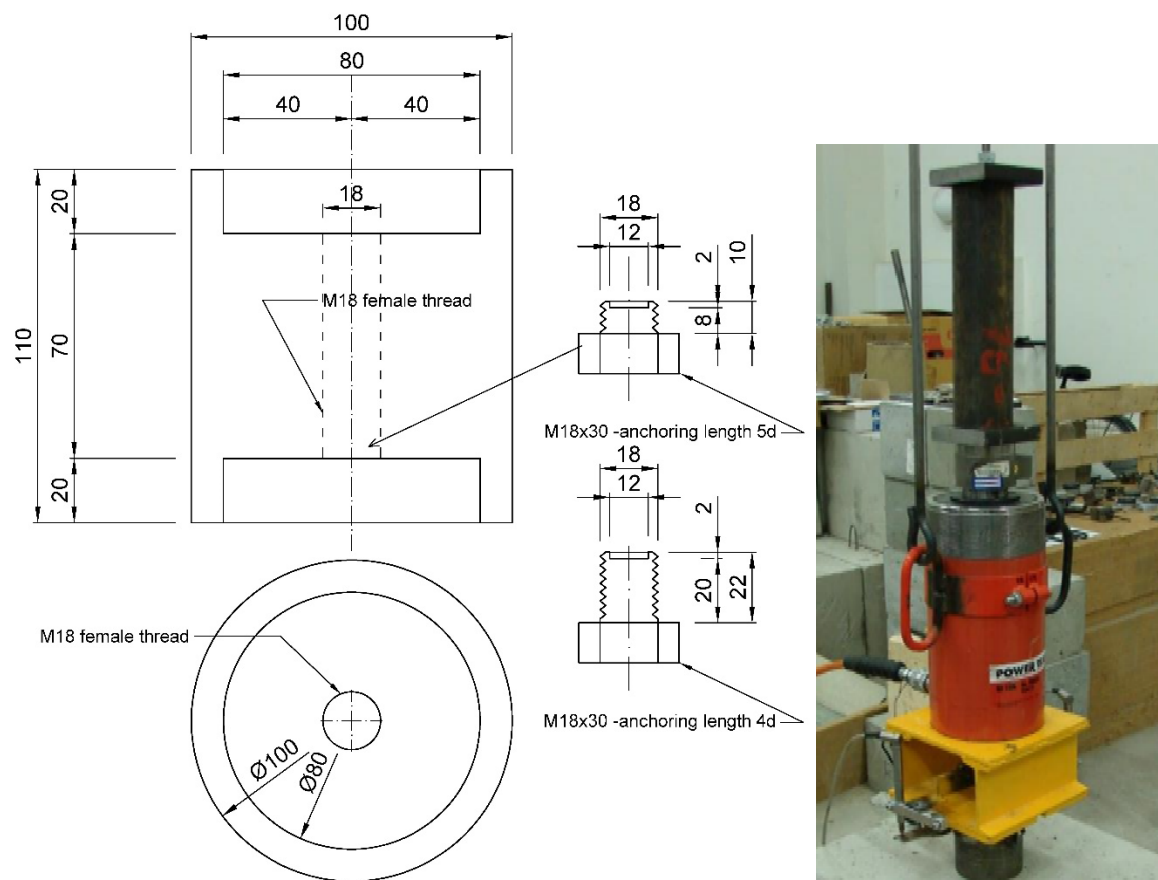


Figure 1. Steel test specimen for anchoring length 4d and 5d

The thickness of the adhesive layer varies due to geometry of both threads. The minimum value of adhesive thickness is 1.3 mm. This is in typical range for standard adhesive anchors.

The steel grade of the anchor bolt itself is another crucial parameter in these tests. The common steel used for anchor bolts is in range from 5.6 to 8.8. Such values are sufficient for standard anchoring. In case of high performance concrete and high quality adhesive, higher steel grades have to be considered even for smaller anchoring lengths. These limits are shown in table 1. Values, which are presented in this table, are evaluated by the use of the formulas for anchor bolt resistance (1) and bond failure (2) according to ETAG.

$$N_{u,k} = A_s \cdot f_{u,k} \quad (1)$$

$$N_{u,k} = \tau_{R,k} \cdot \pi \cdot d \cdot h_{ef} \quad (2)$$

A_s is the minor anchor bolt diameter (tensile area) and h_{ef} is the effective anchoring length. Table 1 shows which steel grade is adequate to use when the bond strengths reach values of 30 and 35 MPa. As it is obvious, in those tests it is necessary to use steel grade 10.9 or rather 12.9.

Table 1. The steel grade limits of anchor bolt

| | | | Characteristic anchor bold resistance (ETAG) | | | |
|---------------------|-------------------|--|--|-------|--------|--------|
| | Ultimate Strength | Yield Strength | d [mm] | 10 | 12 | 16 |
| | $f_{u,k}$ [MPa] | $f_{y,k}$ [MPa] | | | | |
| Steel grade 5.6 | 500 | 300 | $N_{u,k}$ [kN] | 29.00 | 42.15 | 78.50 |
| Steel grade 8.8 | 800 | 640 | $N_{u,k}$ [kN] | 46.40 | 67.44 | 125.60 |
| Steel grade 10.9 | 1000 | 900 | $N_{u,k}$ [kN] | 58.00 | 84.30 | 157.00 |
| Steel grade 12.9 | 1200 | 1080 | $N_{u,k}$ [kN] | 69.60 | 101.16 | 188.40 |
| | | | | | | |
| Bond Strength [MPa] | 35 | Characteristic anchor resistance-bond failure (ETAG) | | | | |
| Diameter of bolt | | | d [mm] | 10 | 12 | 16 |
| Anchoring length | d multiple | | | | | |
| 4d | 4 | | $N_{u,k}$ [kN] | 43.98 | 63.33 | 112.59 |
| 5d | 5 | | $N_{u,k}$ [kN] | 54.98 | 79.17 | 140.74 |
| 6d | 6 | | $N_{u,k}$ [kN] | 65.97 | 95.00 | 168.89 |
| 7d | 7 | | $N_{u,k}$ [kN] | 76.97 | 110.84 | 197.04 |
| 8d | 8 | | $N_{u,k}$ [kN] | 87.96 | 126.67 | 225.19 |
| | | | | | | |
| Bond Strength [MPa] | 30 | Characteristic anchor resistance-bond failure (ETAG) | | | | |
| Diameter of bolt | | | d [mm] | 10 | 12 | 16 |
| Anchoring length | d multiple | | | | | |
| 4d | 4 | | $N_{u,k}$ [kN] | 37.70 | 54.29 | 96.51 |
| 5d | 5 | | $N_{u,k}$ [kN] | 47.12 | 67.86 | 120.64 |
| 6d | 6 | | $N_{u,k}$ [kN] | 56.55 | 81.43 | 144.76 |
| 7d | 7 | | $N_{u,k}$ [kN] | 65.97 | 95.00 | 168.89 |
| 8d | 8 | | $N_{u,k}$ [kN] | 75.40 | 108.57 | 193.02 |

The progress of the test itself is closely described in [3, 4]. In principle, the bond stress is evaluated as a peak value of shear stress on the contact with the bolt diameter d , when the anchor bolt is loaded by tension force.

3. Preparation of Adhesives specimen

The adhesives used in presented tests were chosen due to the high demands on the final strength characteristics. Therefore, the epoxy resin adhesive was tested. Another set of tests were performed with mixtures of vinyl ester resins, which are more capable for hardening in low temperatures.

Resins, which were considered for testing, are summarised in table 2. For their strength characteristics, the CHS-EPOXY 531 and Derakane 411 were tested.

Table 2. Resins considered for testing

| | CHS-EPOXY 512 | CHS-EPOXY 517 | CHS-EPOXY 531 |
|--|--------------------------|--------------------------|--------------------------|
| Dynamic viscosity, 25°C (mPa·s) | 2500 | 950 | 1500 |
| Tensile strength (MPa) | 25 | 40 | 50 |
| Bending strength (MPa) | 40 | 80 | 90 |
| Shrinkage (%) | 0,4 | 0,3 | 0,3 |
| Epoxy equivalent (g·mol⁻¹) | 208-233 | 213-233 | 175-182 |

| | Derakane 411 | Hydropel H034 | Vipes F085 |
|--|---------------------|--------------------------|-------------------|
| Dynamic viscosity, 25°C (mPa·s) | 430 | 575 | 500 |
| Styrene (%) | 33 | 34 | 32 |
| Tensile strength (MPa) | 90 | 80 | 77 |
| Tension modulus (GPa) | 3,3 | 4 | 3,7 |
| Bending strength (MPa) | 145 | 107 | 148 |
| Bending modulus (GPa) | 3,4 | 4,1 | 3,7 |
| Shrinkage (%) | 7,5 | 7,8 | 7,4 |
| Glass transition temperature (°C) | 135 | 107 | 119 |

For the epoxy resin CHS-531, the hardener P11 was used. For vinyl ester resin, Deracane 411, the combination of reaction initiator dibenzoylperoxid (DBP) and high speed accelerator dimethylparatoluidine (DMPT) was used. The basic mixtures are in table 3.

Table 3. Basic mixtures of adhesives

| Mixture | Compound | Weight (g) |
|----------------|-----------------|-------------------|
| 531 | CHS-Epoxy 531 | 100 |
| | P11 | 12 |
| Mixture | Compound | Weight (g) |
| Derakane 411 | Derakane 411 | 100 |
| | DBP | 1.5 |
| | DMPT | 0.5 |

One of the main disadvantages of vinyl ester resin is the relatively high shrinkage effect. For the Derakane 411, it is about 7.5 %. The most common way to reduce shrinkage is to use a filler. This also leads to cost reduction, because the filler is usually cheaper than the resin. Another mixture was prepared with the use of milled limestone with a fraction of 0 – 0.5 mm.

An appropriate type of filler could have a positive effect on the strength characteristic. Some mixtures of epoxy resin were prepared with different amounts of waste carbon fibres. Recycled carbon fibres were milled to 100 µm of length and 6 µm of thickness. Those mixtures are summarised in table 4.

Table 4. Mixtures of adhesives with different filler type

| Mixture | Compound | Weight (g) |
|--------------------|----------------------|------------|
| 531 - V80 | CHS-Epoxy 531 | 100 |
| | P11 | 12 |
| | milled limestone | 400 |
| Derakane 411- V80 | Derakane 411 | 100 |
| | DBP | 1.5 |
| | DMPT | 0.5 |
| | milled limestone | 400 |
| 531 - C10 | CHS-Epoxy 531 | 100 |
| | P11 | 12 |
| | Milled carbon fibres | 10 |
| Derakane 411 - C10 | Derakane 411 | 100 |
| | DBP | 1.5 |
| | DMPT | 0.5 |
| | Milled carbon fibres | 10 |
| 531 - C30 | CHS-Epoxy 531 | 100 |
| | P11 | 12 |
| | Milled carbon fibres | 30 |
| 531 - C50 | CHS-Epoxy 531 | 100 |
| | P11 | 12 |
| | Milled carbon fibres | 50 |

The compounding is the most critical part of the specimen preparation process. All compounds have to be mixed very well. Therefore, the laboratory dispersant with the speed of 8000 rpm was used for basic compounds. The filler was mixed by the help of the kneader with 50 rpm.

4. Results

In the following graphs, the load deformation diagrams are presented. There is a vertical deformation of the anchor bolt on the horizontal axis. This displacement was measured on the top end of anchoring length. On the vertical axis, there is the bond stress evaluated for the interface between adhesive and anchor bolt. The anchoring length was in all tests equal to 4 multiple of anchor bolt diameter and the steel grade was 12.9. At least 4 tests were made for each mixture.

Figure 2 shows the result comparison between 531 and 531-V80 mixtures and the figure 3 the comparison between Derakane 411 and Derakane 411-V80 mixtures. The effect of the milled limestone as a filler is evident. There is a significant reduction of shrinkage together with the reduction peak strength approximately by 30%.

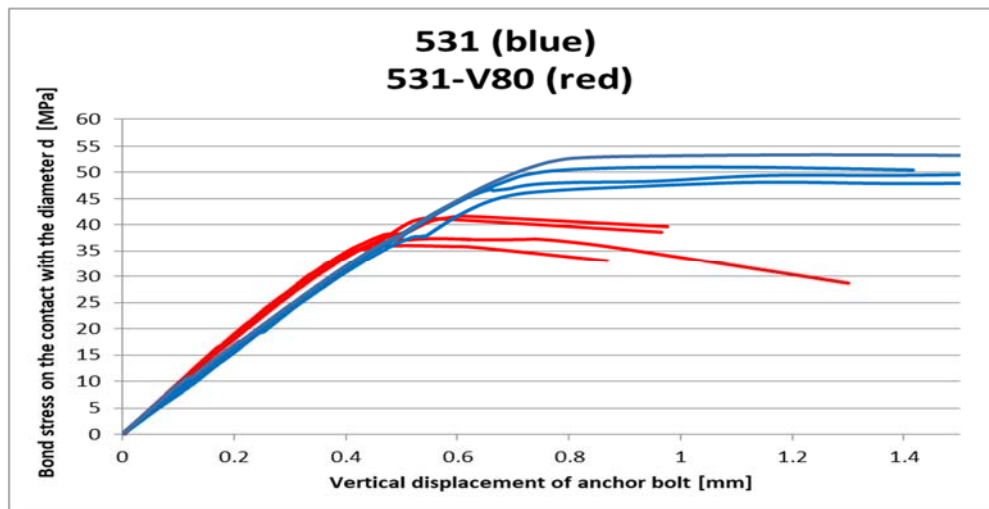


Figure 2. Comparison of epoxy 531 with and without milled limestone filler

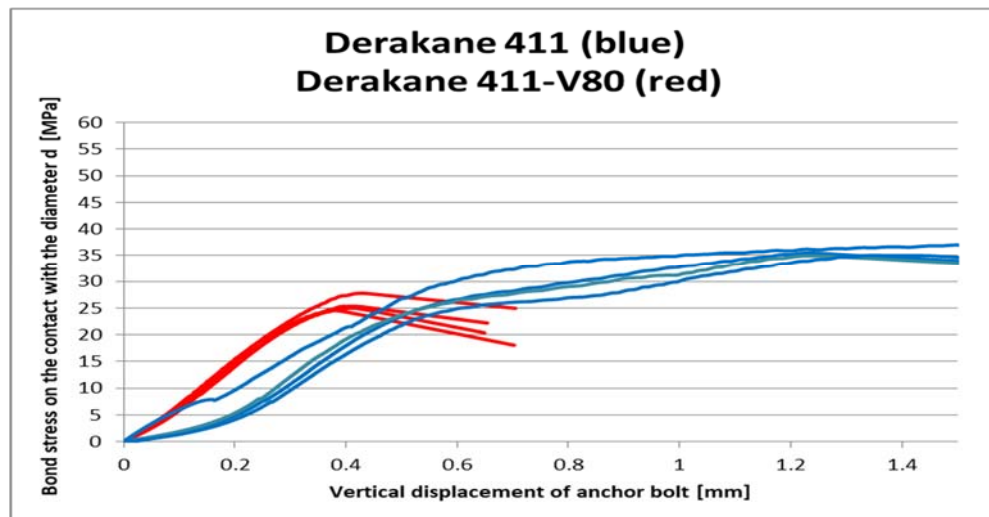


Figure 3. Comparison of Derakane 411 with and without milled limestone filler

The effect of shrinkage reduction is visible also on the specimen after the failure. Figure 4 shows the difference between Derakane 411 and Derakane 411-V80 after the test. Due to shrinkage effect, the adhesive is separated from the anchor bolt for Derakane 411 mixture.



Figure 4. Derakane 411 (left); Derakane 411-V80 (right); specimens after failure

Figure 5 shows the results of Derakane 411 vs Derakane 411-C10. In this case, the effect of a small amount of milled carbon fibres is very insignificant. The reduction of shrinkage is only small.

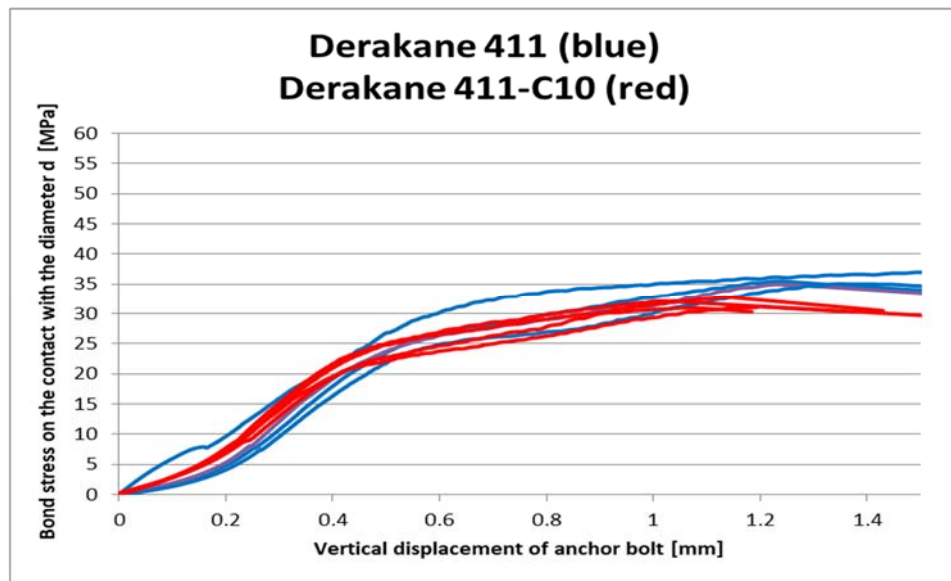


Figure 5. Comparison of Derakane 411 with Derakane 411-C10 – carbon fibres filling

Figure 6 shows the epoxy 531 after the failure with comparison to 531-C10.



Figure 6. Epoxy 531 (left); 531-C10 (right), specimens after failure.

Figure 7 summarises result comparison of epoxy 531 with different amounts of milled carbon fibres filling. In this case, it is obvious that the improvement in the linear part of the load deformation diagram is only very small and the final peak value of strength is slightly reduced.

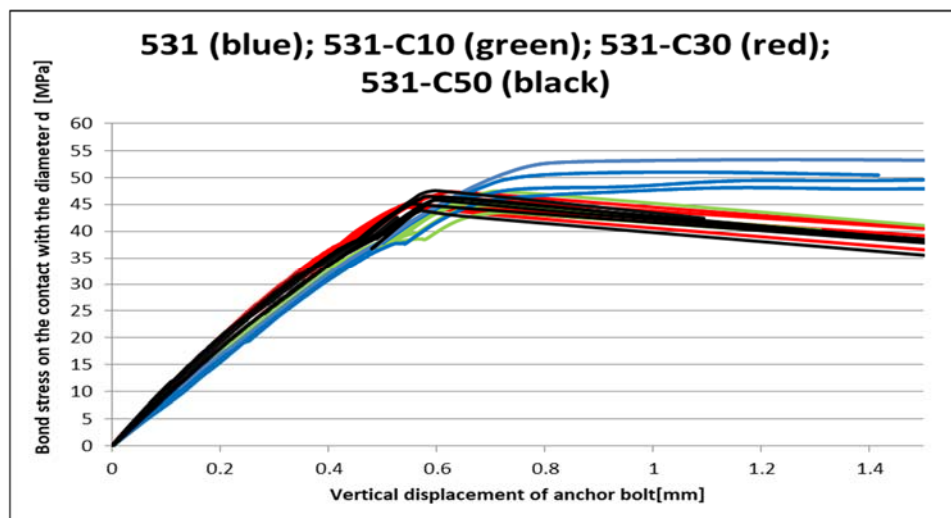


Figure 7. Comparison of epoxy resin 531 with different amounts of carbon fibres filling

5. Conclusions

The strength characteristics of the adhesive itself are the crucial parameter for bond strength failure and for the combined concrete-bond failure of bonded anchors. As obvious from results presented in [3] and [4], the adhesive is the weakest material in anchoring system when it is used in high performance concrete. In common anchor configurations, the bond strength values have to reach average values between 30 and 40 MPa. Only in that case and together with use of standard anchoring length, there can be some advantage to use high strength concrete in anchoring. In addition, the steel grade 10.9 or 12.9 has to be used in such conditions. This paper shows the methodology and the results of experiments with appropriate epoxy and vinyl ester adhesives suitable to ensure the high values of bond strength. Results have shown that fillers can effectively reduce the shrinkage effect of vinyl ester resins. In case of limestone, the shrinkage can be reduced to a minimum together with the reduction of the final strength by cca 30 %. Some problems of shrinkage are presented. The positive effect of use of milled recycled carbon fibres as a filler is insignificant. There is a need of further research in this area. Especially the type, shape and the amount of fibres remains one of the problem to solve.

Acknowledgment

This paper has been worked out with the financial support of project FAST-S-18-5550 and the project FV 10317.

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