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BOND STRESS – SLIP BEHAVIOUR OF PRESTRESSING UNITS COATED WITH CORROSION PROTECTION

Abstract

Experimental research of interaction between prestressing units coated with corrosion protection agents and surrounding material has been performed. This paper shows the result from pull-out tests of strands coated with emulsifiable oil and thixotropic compound. Primary goal is to compare bond stress behaviour at different types of specimens with strand coated or not coated with corrosion protection.

Keywords

Bond, anti-corrosion protection, pull-out test, strand.

1 INTRODUCTION

The time between prestressing of tendons and the injection of ducts in concrete post-tensioned bridges may take several weeks. During this time, it is necessary to protect tendons against weathering and atmospheric humidity. Tendons should be protected with various agents, which can influence their bond with a structure.

Bond between prestressing unit and concrete or injection grout may be influenced by the use of corrosion protection emulsions. Most of the post-tensioned concrete bridges are designed with the use of prestressing units with bond, where a full connection between reinforcement and concrete is assumed. Main reasons are as follows:

- protection against corrosion of prestressing units,
- denser distribution of cracks for partially prestress concrete,
- higher resistance for ultimate limit state.

Using prestressing reinforcement with a bond can prevent a sudden failure of a member. In this case, shear stress between reinforcement and concrete (bond stress) reduces the increased tensile stress of the reinforcement in areas near the first crack. Increased tensile stress in reinforcement is developed only at short length and depends on its bond stress. This leads to small elongations and also narrow crack width. Due to the bond stress, the tensile stress in concrete near the crack is almost without changes and grows with the increasing amount of load. Therefore, the other cracks appear close to the first crack. Before the failure of prestressed member with bonded reinforcement, there are many small narrow cracks that slowly lengthen to the compressed edge. The neutral axis moves slowly to the top of the member and so the compressed part of the section is much higher than in a girder reinforced with units without a bond. This also allows much greater

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tensile stress in reinforcement until it slowly reaches the yield strength of the prestressing unit in the crack. After that, the crack opens to such a level that the compressed concrete starts to crush. Therefore, bonds ensure a higher resistance against failures by way of a better utilization of prestressing steel.

2 BOND EXPERIMENTAL TESTS

There are many aspects that affect the bond between prestressing unit and concrete or injection grout of experimental specimens, for example:

- dimensions of the specimen,
- embedment length,
- method of loading.

Experiments usually mean to estimate transmission length and anchorage capacity. Primary goal of our test was to compare bond stress behaviour on different types of specimens with strand coated or not coated with corrosion protection.

2.1 Corrosion protection agents

Two type of corrosion protection agents were tested. The first was emulsifiable oil prepared from non-aromatic mineral oil soluble with raffinates. The main components are sodium sulfonate, polyvalent alcohols and modified derivatives of fatty acids and antioxidants. It serves as a corrosion and oxidation inhibitor. Density of oil is 904 kg/m^3. Concentration by applying was 25%.

The second type of corrosion protection agent was thixotropic compound. It may be used as reliable corrosion protection filling material for various steel elements. It is cold processed, water blocking material based on highly rafined base oil. Also serve as a corrosion and oxidation inhibitor. This compound has zero oil separation in any temperature conditions. Density of compound is 870 kg/m^3 and can be applied by cold pumping.

2.2 Test arrangement

There are several types of test arrangement shown in Fig. 1. It was chosen the method of bond measuring called pull-out test free (Fig. 1a), where the unstressed strand is pulled out from the concrete specimen [1].

The test arrangement is shown in Fig. 2. A part of the test arrangement was a calibrated hollow jack. Cylindrical specimen was fixed and the strand was pulled out with the jack. On the specimen were measured displacements on both ends and also corresponding pulling force.

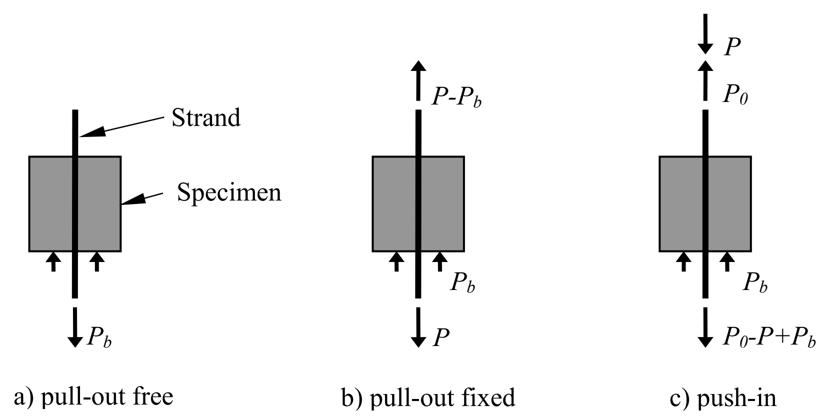

Fig. 1: Schemes of different type of bond testing

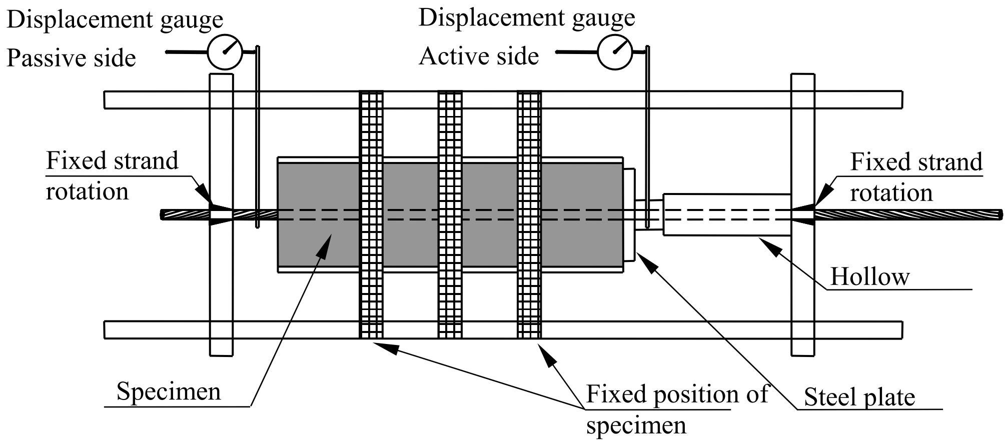

Fig. 2: Scheme of test arrangement

Fig. 3: Test arrangement, detail of passive and active side

2.3 Specimens description

In the experimental program the measuring of the bond on 36 specimens was performed. Twelve specimens were dry with uncoated strands, for 12 specimens emulsifiable oil and for 12 thixotropic compound was applied. Specimens were of cylindrical shape with the length of 600 mm and diameter of 165 mm made from concrete and injection grout placed to the plastic tubes. In their centre, strand ø15.7 (0.62“) with characteristic tensile strength of 1860 MPa were placed. The specimen body was made from concrete of mean cube strength 32.1 MPa. The strand was placed in the centre of the corrugated steel duct. After reaching 28 day strength of the grout, that means approximately 50 MPa, specimens were tested with device constructed for this purpose.

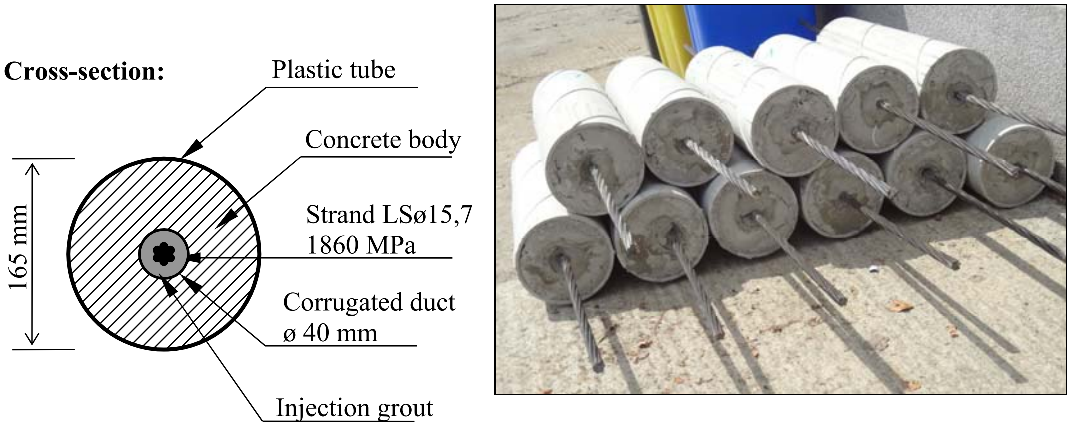

Fig. 4: Specimens

3 DISCUSSION OF RESULTS

Typical mode of failure was represented by longitudinal splitting cracks accompanied with crushed grout wedge around strand on the active pulling side, see Fig. 5. Strands were losing their adhesion if coated with anticorrosion emulsifiable oil. Adhesion losing was obviously due to the fact that the strand was possible to screw out from specimen. Therefore strands were prevented against twisting on both ends of the specimen. Results and comparison of maximal bond stress are shown in Fig. 6.

Fig. 5: Failure mode of specimens with crushed grout wedge

A failure criterion for bond strength is maximum measured load in a pull-out test on strand. Then constant equivalent bond stress was derived from this force. The equivalent area of interface between strand and grout in specimens is 0.02605 m^2. For some pull test, the bond strength is the force recorded when strand draw in certain value, e.g. according to [2] it is 0.25 mm (0.01 in), or according to [3] 2.5 mm (0.1 in). Because our specimens are different and unique from standard ones, it was not provided such criterion for passive displacements.

Maximum bond between strand and surrounding grout was reached in dry type specimens without corrosion protection. The strand was pulled out by 126.1 kN, which is corresponding with constant equivalent bond stress 4.84 MPa. Specimens with strand coated with emulsifiable oil reached average bond stress of 1.61 MPa what is approximately 33 % of dry ones. Specimens with strand coated with thixotropic compound reached average bond stress of 3.98 MPa what is approximately 82 % of dry ones. Bond strength measurements of specimens are shown in Fig. 6.

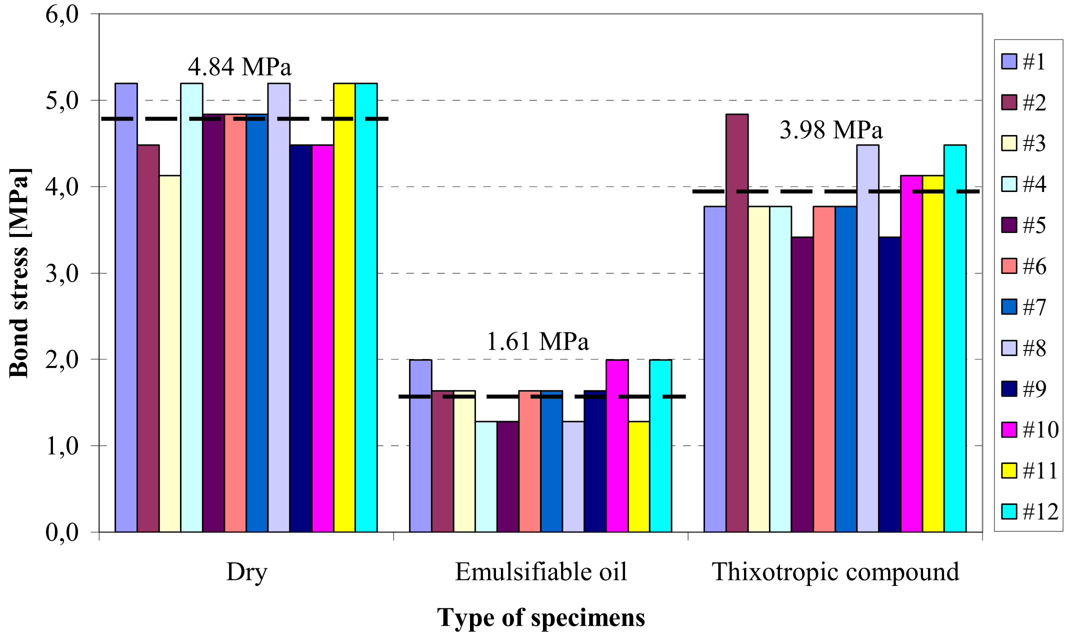

Fig. 6: Maximum bond stress at specimen failure with average values

Another difference except the bond strength can be observed from Fig. 7, Fig. 8 and Fig. 9, where displacements on active and passive side are presented. Measured displacements were summarized by trend lines for active and passive slips and also for all three types of specimens.

Behaviour of dry type specimens may be described as bilinear, see Fig. 7. After rupture of an adhesion, a friction is activated. This debonding occurs at very small slip. Pulling force transmitted before debonding was small and not measurable compared to a force of bond strength. The first part of bilinear trend lines represents a friction due to the radial compressive stress caused by e.g.: irregular shape of strand, varying pitch. After rupture of a friction, a residual bond is provided by mechanical interlock of pulling helical strand. This represents the second part of the trend line presented in Fig. 7. The slope of the second part of trend line compared to the first one is much smaller.

Behaviour of specimens with strand coated with corrosion protection may be described as monolinear, see Fig. 8 and Fig. 9. Compared to the dry type specimen, the first part of trend line is missing. We consider that friction plays only a minor role in this case.

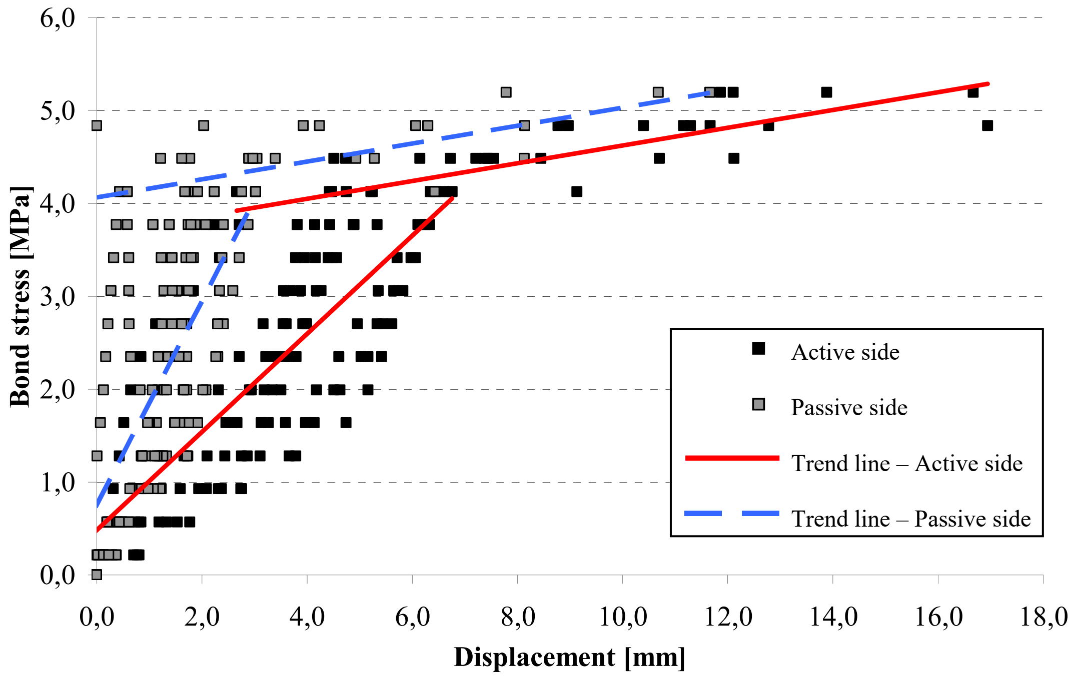

Fig. 7: Bond stress – slip development of "dry" type specimens on active and passive side (strands not coated with corrosion protection agents)

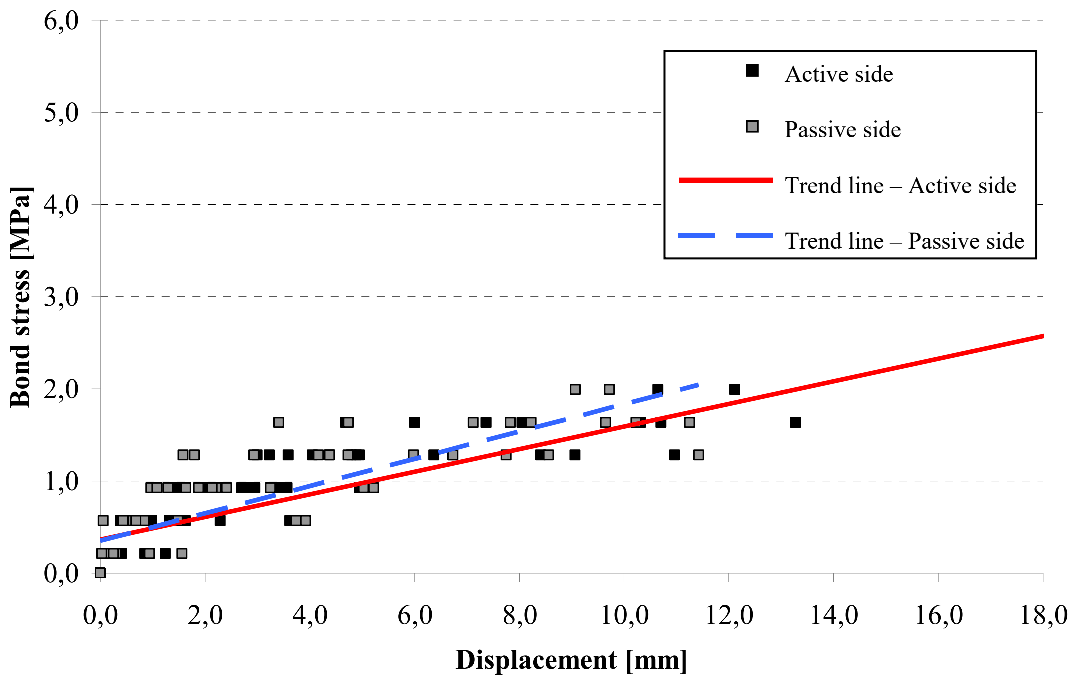

Fig. 8: Bond stress – slip development of "emulsifiable oil" type specimens on active and passive side (strands coated with emulsifiable oil)

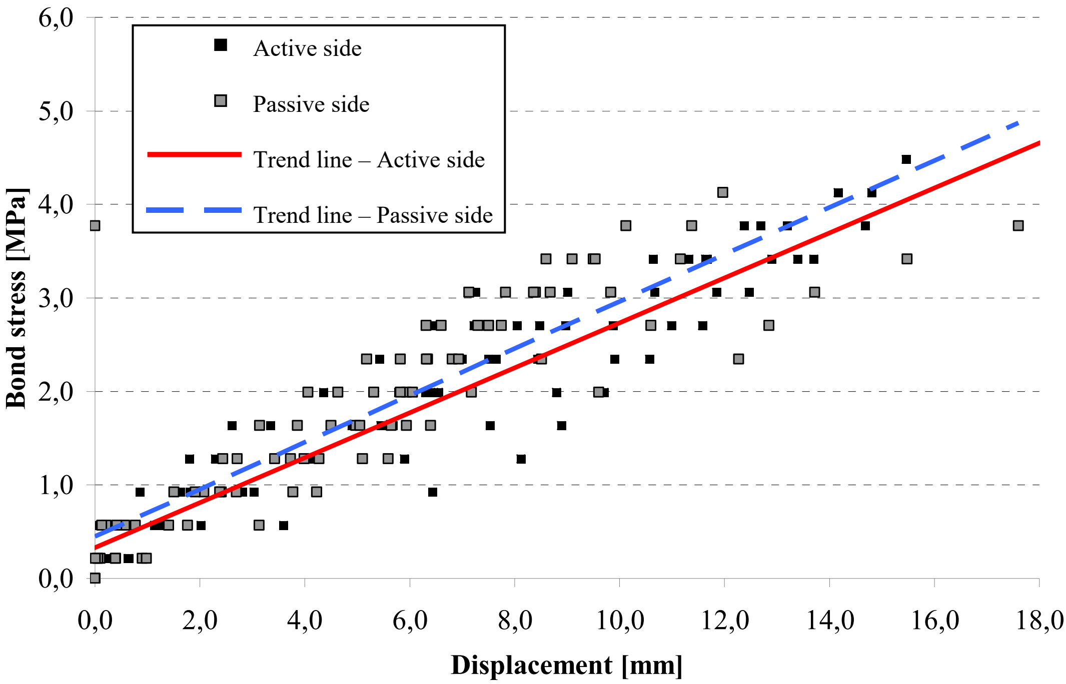

Fig. 9: Bond stress – slip development of "thixotropic compound" type specimens on active and passive side (strands coated with thixotropic compound)

6 CONCLUSIONS

The use of corrosion protection decreases the bond between prestressing units and grout. The results of pull out tests have shown that difference between dry type specimens and specimens with strands coated with corrosion protection is not only in bond strength but also in slip development (bond stress – slip relation). The bond stress of specimens with strands coated with emulsifible oil reached 33 % of dry ones and the bond stress of specimens with strands coated with thixotropic compound reached 82 % of dry ones. Slip of the strands coated with corrosion protection was in the beginning significantly larger compared to dry ones. Bond stress – slip relation of dry specimens may be described as bilinear compared to monolinear bond stress – slip relation of specimens with strands coated with corrosion protection. We assumed that this difference is due to lower friction, particularly in case of strands coated with emulsifible oil.

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REFERENCES

[1] fib Bulletin 10. *Bond of reinforcement in concrete. State-of-art report*. Lausanne : *fédération internationale du béton*, 2000. 434 p. ISBN 978-2-88394-050-5.

[2] ASTM A981-97. *Standard Test Metod for Evaluating Bond Strength for 15.2 mm diameter prestressing steel strand, grade 270, uncoated, used in prestressed ground anchors.* United States, 2002.

[3] LÜTHI, T., BREEN, J. E., et al. *Factors affecting bond and friction losses in multi-strand post-tensioning tendons including the effect of emulsifiable oils : technical report*. Centre for Transportation Research at The University of Texas at Austin, TxDOT, 2005, 174 p.

[4] MARTI, P., ULLNER, M., et al. Temporary corrosion protection and bond of prestressing steel. *ACI journal*. Warsaw, Poland: Versita, 2008, Vol. January-February, pp. 51-59. ISSN 0889-3241.

[5] TEPFERS, R. 1973. *A theory of bond applied to overlapped tensile reinforcement splices for deformed bars* : dissertation thesis. Chalmers University of Technology at Göteborg, Sweden: CUT, 1973, 328 p.

[6] SALCEDO-RUEDA, E., SCHOKKER, A.J., et al. *Bond and Corrosion Studies of Emulsifiable Oils Used for Corrosion Protection in Post-Tensioned Tendons* : research report, Pennsylvania: 2003, 32 p.

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