CHEMICAL ENGINEERING TRANSACTIONS
VOL. 62, 2017
A publication of AIDIC
The Italian Association of Chemical Engineering
Online at www.aidic.it/cet
Guest Editors: Fei Song, Haibo Wang, Fang He

ISBN 978-88-95608- 60-0; **ISSN** 2283-9216
DOI: 10.3303/CET1762173

Study on Fatigue Damage Law of Bonding between Steel Strand and Concrete under Corrosive Environment of Chloride

Yajun Zhao[a,b], Yuanming Dou[a*]

[a]School of Civil and Transportation，Hebei University of Technology, Tianjin 300401, China
[b]School of Civil Engineering, Hebei University of Engineering, Handan 056038,China
douym@126.com

In this paper, based on the corrosion of corrosive environment, the characteristics of prestressed concrete structures with bonded steel strand were studied. It can provide a reference for the durability evaluation and design of prestressed concrete structures. The damage characteristics and failure characteristics of concrete and steel strand were analyzed by long-term fatigue loading of corrosion. Pre-stressed concrete bonded specimen forms corrosion fatigue damage, and the static drawing test was carried out. The characteristics of slip curve and the strength of bond strength with corrosion and fatigue were analysed. The fatigue stress and corrosion fatigue strength factors of the bond fatigue all showed exponential decline. By fitting the test results, the prediction model of the bond life with fatigue stress amplitude and corrosion fatigue strength factor is established.

1. Introduction

As we all know, due to the combined advantages of both concrete and steel, the cost of reinforced concrete structure is relatively low, the material is easy to get and durable, therefore, it is widely used.
Compared to the short history of masonry and wood structure, the development of reinforced concrete structure is extremely rapid (Koga et al., 1975). In the initial stage of using of reinforced concrete structurein the late 19th century, due to the constraints of materials at that time, reinforced concrete structure is mainly used for small components (plate, beam) production. At the beginning of the 20th century, reinforced concrete and concrete materials have been used in a large scale, and it enhanced the strength of reinforced concrete structure in engineering sector (Lin, 1999; Apostolopoulos and Michalopoulos, 2007).
Compared with the ordinary reinforced concrete structure, the prestressed concrete structure not only has the advantages of large capacity, good performance, superior performance, high durability, light and beautiful, but also is more economical and energy-saving. It effectively improved the performancve of the reinforced concrete structure, and broadened the scope of its application (He et al., 2010). For high (high-rise buildings, high-rise buildings), large (large span, large space structure), heavy (heavy load structure), and special (special structure and special purpose) projects, prestressed concrete structure has become one of the most important structural forms, which cannot be underestimated.
Compared with the ordinary reinforced concrete structure, the modern prestressed concrete structure has the advantages of high strength, good compactness, small cracks and thicker thickness of the concrete protective layer, so it is generally has longer durability. But this does not mean that the prestressed structure is perfect, there is still possibility for durability failure, but the possibility is much smaller than that of ordinary concrete structures (Khabaz, 2010). The structure of the prestressed structure in the erosion environment (such as carbonation, chloride ion erosion, freezing and thawing, chemical media erosion, etc.) will be internally damaged and the damage will be gradually accumulated until before the final corruption.
The reasons for the corrosion of the prestressed tendons include (Sancak et al., 2011)the use of corrosion-sensitive prestressed tendons, tension or improper anchorage, erosion environmental and erosive materials,

Please cite this article as: Yajun Zhao, Yuanming Dou, 2017, Study on fatigue damage law of bonding between steel strand and concrete under corrosive environment of chloride, Chemical Engineering Transactions, 62, 1033-1038 DOI:10.3303/CET1762173

humid environment, corrosion protection inappropriate environment and structure, which account for 23%, 15%, 4%, 23%, 24% and 9%, respectively, as shown in Figure 1.

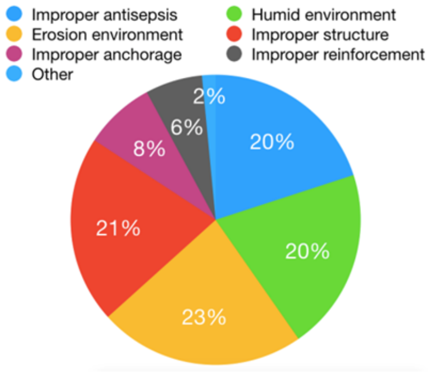

Figure 1: Classification on Damage Accident of Prestressing Reinforcement

Prestressed steel strand is made of high-quality and high-carbon steel structure by hot-rolled wire rod by sorbite treatment, pickling and surface treatment, drawing, twisting, stabilization and other processes (Singh et al., 2014). These fabrication processes have a significant effect on the microstructure of the strand. Under macroscopic state, the corrosion of ordinary steel bars under the erosion of chloride salt is presented in the form of local inhomogeneous pits. And the characteristics of the corrosion resistance of the strand are more obvious, which is characterized by poor corrosion uniformity and serious corrosion pit (Figure 2).

Figure 2: Comparison on corrosion morphology between ordinary steel bar and steel strand

Although the prestressed concrete structure has a strong ability to resist the erosion of the external environment, the previous emphasis on the durability is not enough. A series of accidents happened because of the failure of prestressed concrete structure, which caused by the corrosion of the prestressed steel. According to a survey in 1978, there were 28 engineering accidents due to the corrosion damage of prestressed concrete structure worldwide between 1950 and 1977 (Zhu et al., 2016). Another survey in 1982 showed that there were 50 buildings damaged in the United States between 1978 and 1982, and 10 of them were caused by stress corrosion or hydrogen embrittlement.
In this paper, the corrosion fatigue problems of steel strand and concrete are studied based on the problem of prestressed concrete structure with bonded steel strand in the corrosive environment with chloride salt. The residual fatigue strength of steel strand and concrete under the condition of residual fatigue strength and corrosion condition of corrosion resistance were dealt. Based on the corrosive environment and fatigue load of prestressed concrete structure in practical engineering, a test method was proposed to reflect the corrosion behavior of steel strand in concrete bonded prestressed concrete structure and the bond performance of concrete. Based on the problem of degradation of working performance of prestressed concrete structures under the action of chloride salt erosion and fatigue load, the problems of bond corrosion fatigue of steel strand and concrete were studied. The residual bearing capacity of bonded corrosion fatigue was revealed by experimental study.

2. Experiments

2.1 Test materials

Specimen with C30 strength of concrete, the ratio of cement, sand, stone and water is 1: 1.84: 3.00: 0.53. Cement is 42.5 ordinary Portland cement, while the sand is from the river in Xuzhouwith 10mm-20mm gravels in it. Water is ordinary tap water supplied by Xuzhou water plant. Domestic 15.2 (17) sΦ × 1860 grade strand was used as prestressed tendons.

2.2 Specimen design and production

In view of the corrosion fatigue bonding properties of steel strand and concrete, the design of the specimen should consider the fatigue test and the residual static drawing test. At present, the bond strength commonly used for the determination can be divided into three categories according to the purpose: pull test, tensile test and beam test as shown in Figure3. The design can also be divided into drawing test pieces, tensile test pieces and beam test pieces.

Pull-out test. The purpose of pull-out test is to compare the bond properties of various types of steel bars, and the average bond stress can be pulled out by the pull of the tensile force by the following formula: $\tau = P/\pi dL$

Where, d is the diameter of the bar, L is the embedded length. The displacement gauge between the concrete and the steel can be measured to load the end or end slip τ-s relationship.

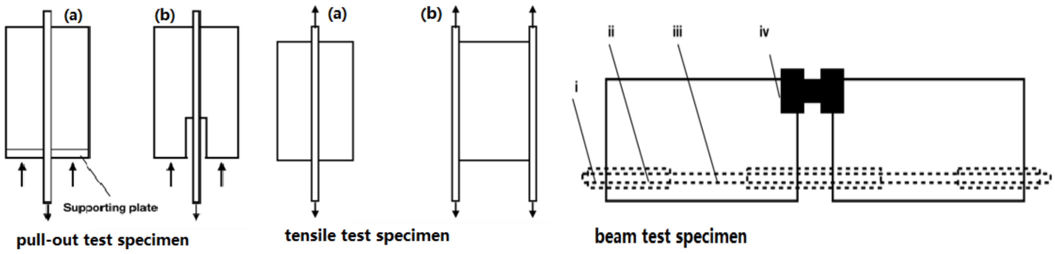

Figure 3: Three kinds of test specimen

2.3 Fatigue loading method and device design

This fatigue test is especially suitable for the long-term fatigue performance test of concrete, such as beam and steel bar which were in civil engineering. It is also applicable to other engineering structures, such as the long-term fatigue test machine (Figure 4) invented by Li's research group (Li et al., 2017). Fatigue performance tests of fatigue load on components were carried out on it.

The fatigue testing machine adopts the low-speed and high-torque motor to drive the turntable. When the turntable rotates, the steel wire rope which is fixed on it is used for telescopic movement to drive the pulley group movement. The stationary pulley group is fixed on the frame together with the corresponding lower beam. The pulley group, together with the corresponding upper beam, can be moved up and down along the interior of the frame, and then can be conveyed to the test piece to form reciprocating loading.

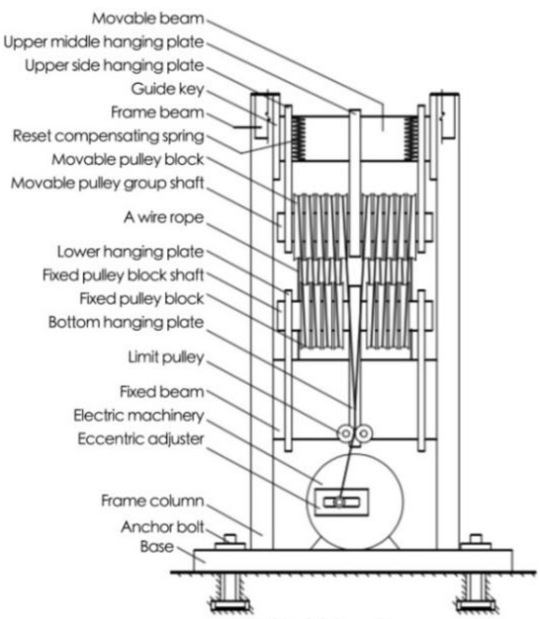

Figure 4: Fatigue machine structure Insert

3. Discussion and analysis

3.1 Reinforcement temperature

After the drawing test, the ultimate bonding force of all specimens and the bond slip curves of some specimens were obtained. According to the measured data, the following different corrosion conditions and different fatigue conditions of the test pieces were compared. The influencing factors include salt loss rate, fatigue stress amplitude and fatigue frequency.

3.2 Effect of salt doping on ultimate bonding stress

The temperature of the reinforcement with a protective layer thickness of 25 mm is the highest, and the steel temperature with a protective layer thickness of 40 mm ranks the second. When the protective layer thickness is 60 mm, the temperature of the steel bar is the lowest. The fire duration is over 90 min, and thetemperatures of steel with a protective layer of 40 mm and 25 mm are nearly the same. This is because the protective layer cracks deep, resulting in heat transfer directly to steel, therefore, the temperature difference is not big.
The limiting bond stresses of the bonded specimen are 0 to 6%, 10%, and 14%, respectively, as shown in Figure 5:

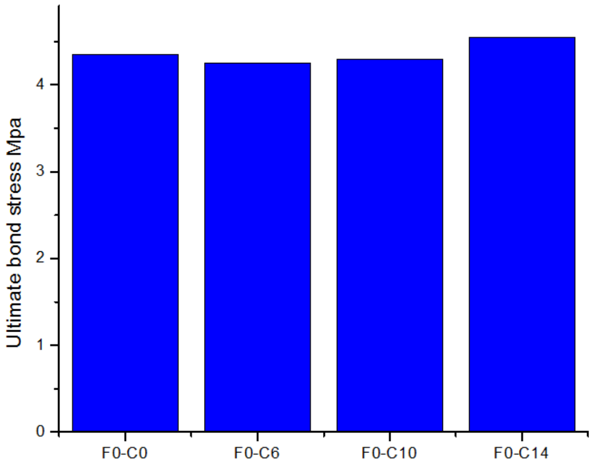

Figure 5: Ultimate bond strength of specimens with different salt rate and no fatigue

According to the above Figure 5, the ultimate bond stress of the specimen with no fatigue showed a tendency to decrease firstly and then increase with the increase of salt concentration. But the overall change was not obvious.
In the case of the same changing trend of corrosion conditions, the ultimate bond stress of the bonded specimen showed a decreasing trend after adding the fatigue effect on the specimen. The combined effect of fatigue and corrosion makes the bonding performance of the bonded specimen significantly degraded.

3.3 Effects of fatigue chlorine tress and fatigue times on limit bond stress

The fatigue stress amplitude of the experimental design was 0, 0.21 MPa, 0.63 MPa and 1.89 MPa respectively. And the fatigue stress amplitude of 1.89 MPa adhesive specimen was set for different fatigue times, and used to observe the number of fatigue on the specimen adhesion degradation. The chorine salt loss rate of the average tensile stress of the specimen is14% and the fatigue stress amplitude is 0, 0.21 MPa, 0.63 MPa and 0.89 Mpa
From Figure 6, it can be found that the distribution of the average ultimate bond stress of the bonded specimen with chlorine salt content of 14% is more discrete due to the use of elemental concrete. However, the average ultimate bond stress increases first and then decreases with the increase of fatigue strength, which is similar to that of parabola. The adhesion rate was 14%. When the fatigue strength factor was 113.4, and the ultimate bond stress reached the maximum, the fatigue stress amplitude was 1.89 MPa and fatigue was 600,000 times.
From the analysis of the ultimate bond stress of all the specimens before, it can be seen that the presence of fatigue does improve the ultimate bond strength of the specimen, but this improvement is not infinite.
The fatigue is accumulated to a certain extent, and then the ultimate adhesion of the specimen will be degraded.

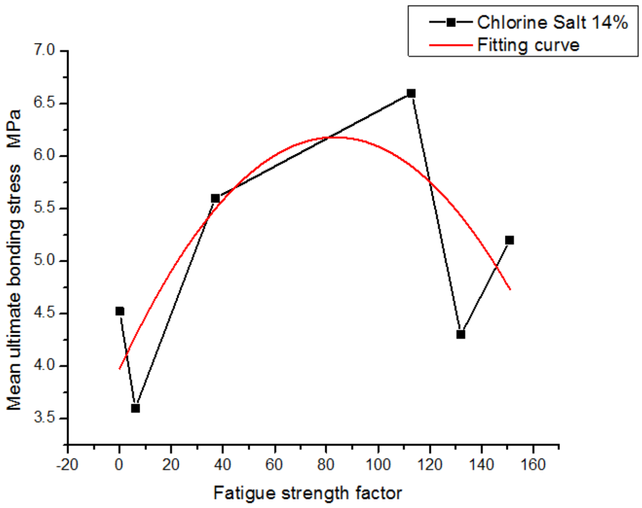

Figure 6: The trend of the average ultimate bond stress with the fatigue strength factor of all 14% NaCl specimens

3.4 Effects of fatigue stress amplitude, fatigue frequency and salt loss rate on the ultimate bond stress

Considering the combined effect of corrosion conditions and fatigue conditions, it is assumed that the corrosion fatigue strength factor is determined by the chlorine salt loss rate and the fatigue strength factor, that is, the product of the two is expressed by both corrosion and fatigue. The coupling effects and the trend of the average ultimate bond stress with corrosion fatigue strength of all corrosion fatigue specimens are shown in Figure 7.

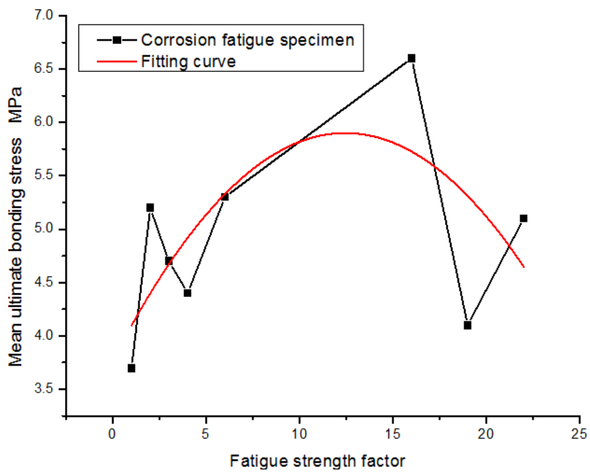

Figure 7: The trend of the average ultimate bond stress with the corrosion fatigue strength factor of all corrosion fatigue specimens

From Figure 7, it can be found that the distribution of the average ultimate bond stress of the corrosion fatigue bonded specimen is more discrete, due to the reason of concrete use. However, the variation law of the specimen with the change rate of 14% is similar to that of the whole specimen. The average ultimate bond stress increases with the increase of the corrosion fatigue strength factor, and increases with the parabola. All the corrosion fatigue bonded specimens were tested, when the corrosion fatigue strength factor is 15.876, the ultimate bond stress reaches the maximum. The salt loss rate is 14%, fatigue stress amplitude is 1.89MPa, and fatigue frequency is 600,000 times.

In the figure, the salt addition rates of S3, S5 and S6 are 6%, 10% and 14% respectively, the fatigue stress amplitude is 0.63 MPa and the fatigue frequency is 300,000 times. From the change trend in the Figure 7, we can see that with the increase of salt concentration, the average ultimate bond stress of the specimen decreases. That is, the ultimate bonding force of the specimen is degraded due to corrosion and fatigue.

From the analysis of the ultimate bond stress of all the specimens before, it can be seen that the presence of fatigue does improve the ultimate bond strength of the specimen, but this improvement is not infinite. When the fatigue accumulates to a certain extent, the ultimate adhesion of the specimen will be degraded. To sum up, from the whole, corrosion and fatigue coupling effect on the bonding effect weakened after the weakening trend. Compared with the steel strand and concrete bonding, after using the constant current method to accelerate corrosion, cement specimen fatigue life is longer than beam fatigue life of the specimens. Damage characteristics of steel strand and concrete were analyzed. Trends of ultimate bond stress with the number of fatigue and mixed salt rate, and characteristics of bond-slip curve were met by servo test and strain test.

4. Conclusion

After the static tensile test of the steel strand in the prestressed concrete beam after the corrosion fatigue, it is found that the maximum bearing capacity of all the strands is reduced to different degrees. The degradation of the maximum tensile strength of strands is more obvious than that of the steel wire and the concrete. And the degree of degradation is more obvious than that in the previous experimental study. It can be concluded that the degradation of the basic properties of the prestressed concrete members is the degradation of the tensile properties of the strand, and the influence of the bonding factors is small. From the analysis of the degradation of the tensile properties and fatigue life of the strand, the control factors of the prestressed concrete members affected by corrosion fatigue are the tensile properties of the strands in the prestressed concrete members. The adhesion between the wire and the concrete is relatively followed.

Acknowledgement

This work was supported by the National Natural Science Foundation of China (51378169).

Reference

Apostolopoulos C.A., Michalopoulos D., 2007, Mechanical Properties of Reinforcing Steel and Fatigue Behavior in Corrosive Environment, Journal of Materials Engineering & Performance, 16(5), 559-566, DOI: 10.1007/s11665-007-9083-6.

Khabaz A., 2010, Influence of chemical bonding of chlorides with aluminates in cement hidratation process on corrosion steel bars in concrete, Hemijska Industrija, 64, 47-51, DOI: 10.2298/HEMIND1001047B.

Koga M., Terasawa M., Asami K., Yoshioka Y., 1975, Studies on the Corrosion Fatigue of Tufftrided Steel: Fatigue Tests in Pure Water and in 3% NaCl Solutions; 1st Report, Journal of the Society of Materials Science Japan, 24, 79-85, DOI: 10.2472/jsms.24.79.

Li F., Y.Qu, Wang J., 2017. Bond life degradation of steel strand and concrete under combined corrosion and fatigue, Engineering Failure Analysis, 186-196, DOI: 10.1016/j.engfailanal.2017.06.036.

Lin C.W., 1999, Effect of chromate conversion coatings with and without poly(acrylic acid) on the press formability, shearing properties and durability of galvanized steel laminates using poly(vinyl butyral) as core material, Journal of Materials Science, 34, 3951-3956, DOI: 10.1023/A:1004691226931.

Sancak E., Simsek O., et al., 2011. A comparative study on the bond performance between rebar and structural lightweight pumice concrete with/without admixture, International Journal of Physical Sciences, 6(14), 3437-3454, DOI: 10.5897/IJPS11.556.

Singh A., Lin Y., Liu W., Deng K., Pan J., 2014. A study on the inhibition of N80 steel in 3.5% NaCl solution saturated with CO 2 by fruit extract of Gingko biloba, Journal of the Taiwan Institute of Chemical Engineers, 45, 1918-1926. DOI: 10.1016/j.jtice.2014.02.001.

XF H.E., Zhao S.G., Leng YB., 2010, Test and Study on Impact of Corrosion on Bond Force between Steel and Concrete, Applied Mechanics & Materials, 36, 176-181, DOI: 10.4028/www.scientific.net/AMM.36.176.

Zhu F., Ma Z., Zhao T., 2016. Influence of Freeze-Thaw Damage on the Steel Corrosion and Bond-Slip Behavior in the Reinforced Concrete, Advances in Materials Science and Engineering, (3), 1-12, DOI: 10.1155/2016/9710678.