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Study on fire endurance of chemical post-installed rebar member under coupling condition

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In order to study the fire endurance of chemical post-installed rebar member under coupling condition, the depth of embedded steel bars (15d, 20d) and the coverage coats (25 mm, 40 mm, 60 mm) are investigated. Six specimens exposed to the ISO834 standard temperature were tested. In the fire test of embedded steel bars, the load applied on the specimens was about 10 percent of the designed, and then the load was added to make the specimens Invalid after specified time. The results show that the depth of embedded steel bars and the thickness of protective layer have important influence on the ultimate bearing capacity of the steel bars in the fire. A constant load temperature rise test has been carried out, in which the load applied on the specimens was about 80 percent of the designed load and was kept constant until the specimens was broken. The results show that when the thickness of protective layer is less than 40 mm, the depth of embedded steel and the thickness of protective layer have an important influence on the fire resistance; When the thickness of protection layer is more than 40 mm, the influence on the fire resistance is greater than the thickness of the protective layer.

1. Introduction

In the fire, beams, plates and columns as basic elements of concrete buildings are subject to varying degrees of impact. Technique of Chemically-planted Steel Bar can be applied to these basic components such as frame column rooting, column beams and floor filling, etc. It can be seen that the chemical rebar planting technology is used in the component as well as connection of the component, and the most important is still used in the node of the component. The node is a very important component in the structure, and the requirement of the node is very strict in the design process, For example, structural seismic design requires that “nodes is the first and component is secondary ". Similarly, the fire resistance design of the structure will also put forward corresponding requirements to the nodes. Thus, it is of great practical significance to study the fire resistance of joints made of chemical rebar planting technology.

Considering the development of anchorage technology of white chemically-bonded rebar, domestic and foreign scholars analysed the bearing capacity of bonded rebar under normal temperature (Shu and Zhang, 2008). What’s more, the bond stress and slip analysis and anchorage fatigue analysis were also investigated (Zou and Lu 2011). However, the existing reinforcement design criterion does not consider the influence of high temperature on the rebar planting (Li and Chen, 2015), which makes the application of reinforcement technology in the reinforcement and reconstruction project lack of reasonable and effective design guidance (Xie et al., 2015). Some foreign manufacturers of rebar planting have done relevant researches in this field. In China, the pullout capacity test and fire resistance test of single steel bar in fire were carried out at Tongji University. Experimental study on mechanical behavior of steel bar bonded slip has been carried out at high temperature in China University of Mining and Technology (Yuan et al., 2008). However, the studies above do not relate to the bond slip relationship of steel bars in high temperature, and all of them are experimental studies of test specimens. In this work, the pullout test of steel bar specimens at different temperatures (25~200 ℃) has been carried out. The law of the adhesive force with the temperature and the bond slip relationship of the adhesive of the steel bar under different temperatures are studied; In addition, the ultimate bearing capacity and the fire resistance limit of the connection component of the steel bar in the fire are studied by the fire test which includes 2 groups of steel bars.

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2. Experiments

2.1 Design and manufacture of test pieces properties

In this experiment, 6 reinforced concrete members were placed, and two influencing factors（the thickness of the protective layer and the depth of the planted steel） and three kinds of protective layers of different thickness (25 mm, 40 mm and 60 mm) were considered. Two kinds of the depth of embedded steel bars (15d, 20d) were investigated. Specimen size and reinforcement were shown in Figure 1. The specimens are divided into two phases, the construction of reinforced concrete foundation is carried out first, and after the maintenance of the base material, the construction of the embedded beam is then carried out. The mechanical properties of the material are shown in Table 1.

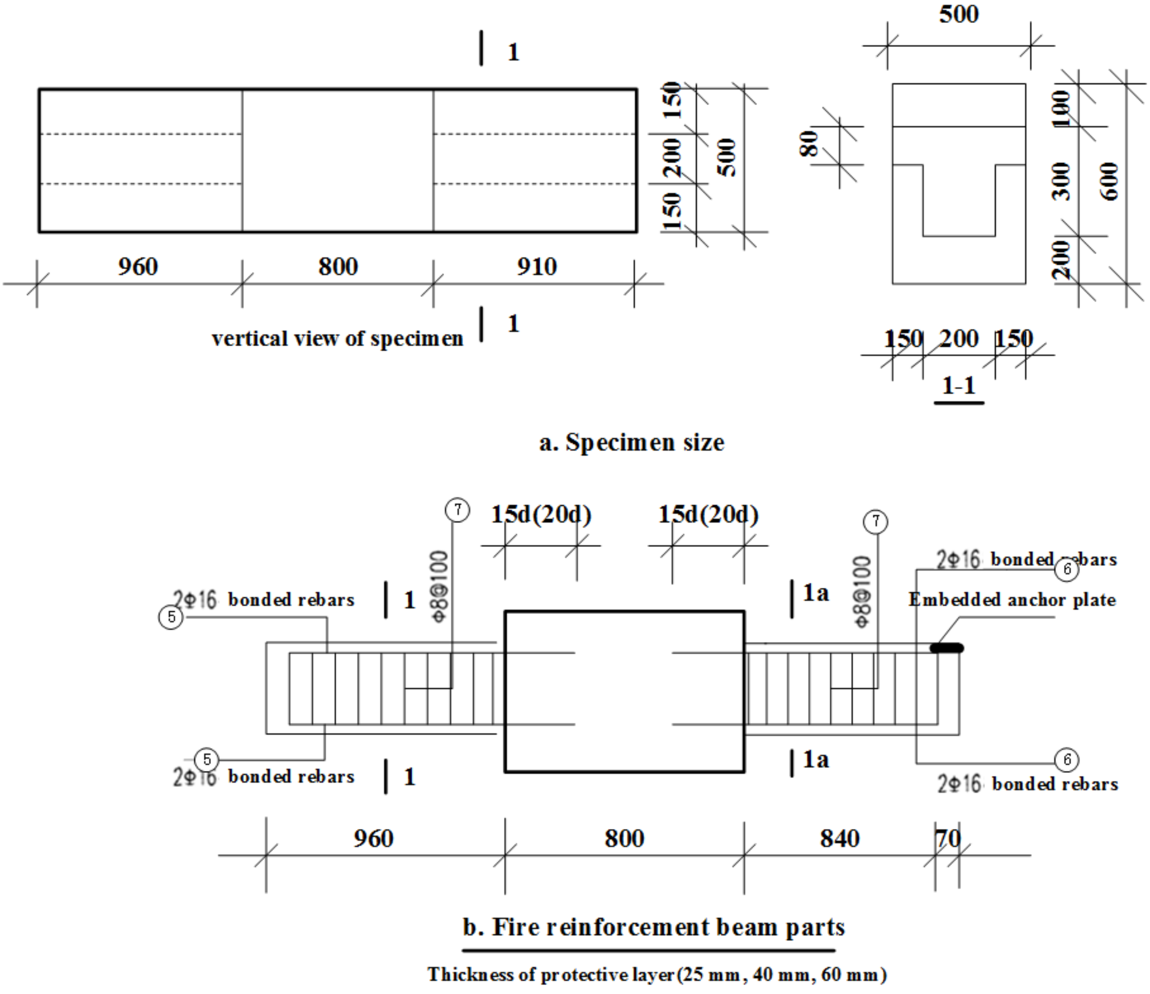

Figure 1: Specimen size and reinforcement

Table 1: Mechanical properties of material

Material	*Material specification*	*Axial compressive strength*	*Modulus of elasticity*
Base concrete	*C30*	*26.5 MPa*	*31000*
Concrete beam	*C30*	*31 MPa*	*33000*
Bonded rebars	*HRB335(d=16 mm)*	*338.6 Mpa (yield strength)*	*190000*

2.2 Measurement indicators and test equipment

According to the purpose of the test, the main indexes of the test include applied load, temperature of furnace, temperature of steel bar, temperature of embedded glue and fire resistance, etc. Loading fire schematic (Liu, 2013) is shown in figure 2.

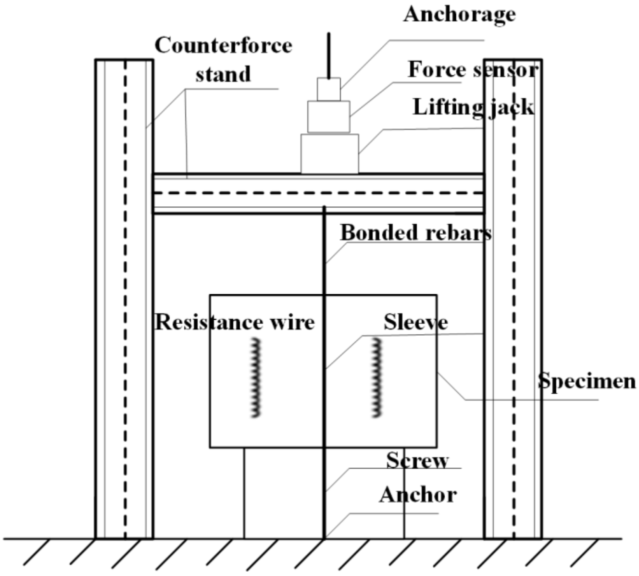

Figure 2: Loading fire schematic

2.3 Test process

When the fire test is carried out, the side support is supported by two vertical rods, and the other side adopts a rolling support. Install displacement sensor at specified position. Set up ISO834 (Zhao et al., 2005) standard and heat the reinforced concrete embedded member by open flame. Load the base material by hydraulic jack and keep the load constant during heating. The applied load is approximately 80% of the design load at normal temperature. When the specimen material displacement reaches 100 mm andthe specimen reaches the refractory limit, close the specimen from the one-way oil inlet valve load. When all the specimens are damaged, stop heating.

3. Discussion and analysis

3.1 Reinforcement temperature

The temperature of the steel bar varies with time as shown in Figure 3. According to Figure 3, the temperature of the steel bars did not rise and remained at room temperature in the first 10 min. Although the furnace temperature has begun to increase, the heat cannot be immediately transferred to the steel bar because the concrete is a poor conductor of heat, so the temperature of the steel bar did not rise immediately, and basically maintained at room temperature. Subsequently, the temperature of rebar began to increase nonlinearly, and the temperature of the reinforcing steel increased at the beginning, and then the temperature of the reinforcing steel slowed down. This is due to the surface cracks of concrete after fire, accelerate the heat transfer and reinforced low temperature specific heat is small, the temperature began to increase rapidly. Because of the high temperature, the reinforced heat capacity becomes larger, so the steel temperature increased slowly.

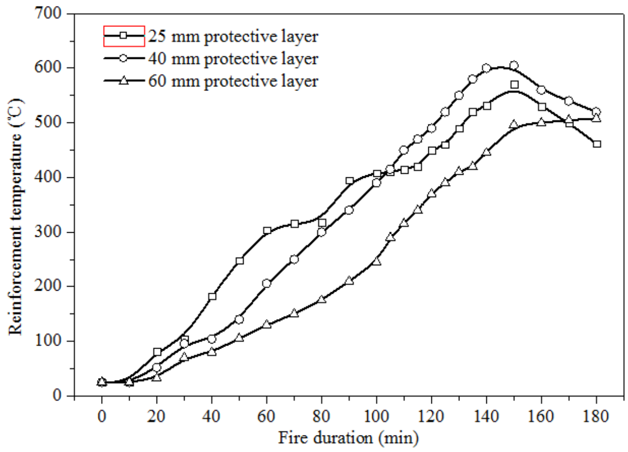

Figure 3: The temperature of the steel bar varies with time

As can be seen from Figure 3, the temperature of the reinforcement with a protective layer thickness of 25 mm is the highest, the steel temperature with a protective layer thickness of 40 mm is the second, and that of the steel bar with a e protective layer thickness of 60 mm is the lowest. The fire duration is over 90 min. The steel temperature of steel with a protection protective layer of 40 mm and 25 mm is nearly the same, this is due to the deep cracks of the protective layer, resulting in direct heat transfer to steel, therefore, the temperature difference is not big but basically the same.

3.2 Temperature of bar planting glue

As can be seen from Figure 4, with the increase of the fire time, the temperature of the bar cement rises nonlinearly. At the beginning of 20 min, the temperature of the bonding bar under different protection layers is basically the same, without rising and keeping the room temperature unchanged. This is because the concrete is a poor conductor of heat, although the furnace temperature has begun to rise, the heat has not been transferred to the planting bar, therefore， the temperature of the adhesive glue did not rise.

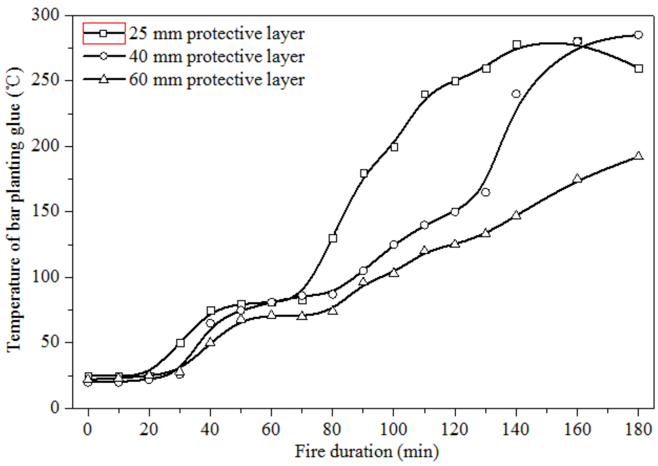

Figure 4: The temperature of the steel bar with different protective layer varies with time

When the fire duration is over 20 min, adhesive temperature began to rise. The adhesive temperature of the 3 protective layers are different, which is due to slow heat transfer, therefore, the three temperature did not increase compared to. When the fire time is more than 40 min, a horizontal section of 20~30 min appears on the temperature curve. The temperature of the horizontal section is between 70 and 88 degrees centigrade. This is due to the evaporation and vaporization of moisture in the concrete, which takes away most of the heat, resulting in a horizontal section of the interior of the concrete and the glue at the same time. After the horizontal section, the temperature of the embedded steel bar started to rise at a faster speed, and the temperature of the steel bar with thinner protection layer was higher, and that of the steel bar with thick protective layer was lower.

As shown in Figure 4, adhesive temperature of bonded rebar with 40 mm protection layer obviously speeds up at the heating rate, which is due to the combination of new and old concrete cracks. Heat is directly transferred to the adhesive and steel instead of the protective layer of the concrete, therefore, the temperature of the latter rises faster.

3.3 Fire resistance limit

The change of the fire resistance limit of the steel bar with the protective layer is shown in Figure 5. It can be seen from figure 5 that the fire-resistant limit increases nonlinearly with the increase of the protective layer when the steel bar is of the same depth. When the protective layer thickness is less than 40 mm, the fire resistance limit affected by the thickness of the layer is higher; when the protective layer thickness is larger than 40 mm, the fire resistance limit affected by the layer thickness is lower, as shown in the figure 5. At the beginning, the slope of the curve is larger, however, when the layer thickness of steel is more than 40 mm, the slope of curve decreases.

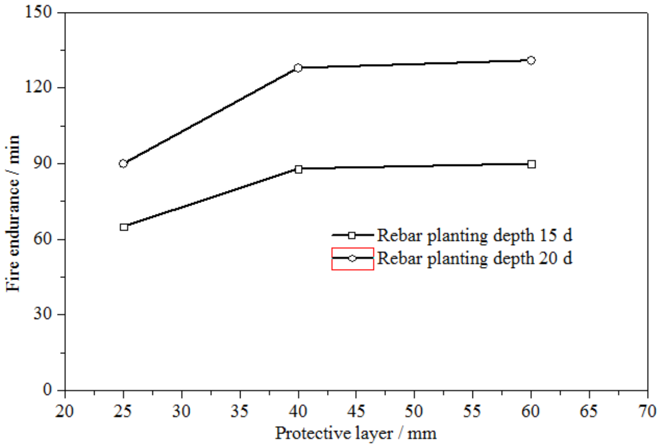

Figure 5: The change of the fire resistance limit of the steel bar with the protective layer

The fire-resistant limit of the embedded steel bars with different reinforcement depth is different in terms of the thickness of the protective layer. When the protective layer thickness is less than 40 mm, the fire-resistant limit of 20 d tensile fire resistance parts increases with the increase of the thickness of the protective layer at a fast speed, while the that fo 15 d tensile fire-resistance parts increased with the increase of the thickness of the protective layer at a slow rate, which corresponds to the fact that curve slope of 20 d specimen e is greater than 15 d specimen. When the protective layer is larger than 40 mm, the fire resistance of 15 d and 20 d rebar specimens is less affected by the thickness of the layer, and the slope of the curve is smaller

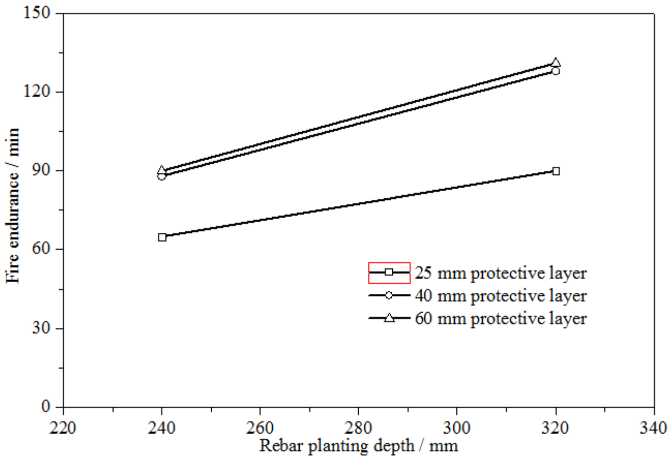

Figure 6: the influence of the embedded steel bar on the fire resistance of the steel bars

The diagram of the influence of the embedded steel bar on the fire resistance of the steel bars is shown in figure 6. As can be seen from Figure 6, when the thickness of the protection layer is the same, the fire resistance limit of the rebar embedded test piece increases with the increase of the rebar planting depth;when the thickness of the protection layer is different, and the influence of the embedded steel depth on the fire resistance is different. The depth of embedded steel bars has different influence on the fire resistance limit of the embedded steel bars under different protection layers. When the protective layer is thinner, the depth of the embedded steel bars has less influence on the fire resistance. With the thickness of protective layer increases, the influence of the depth of embedded steel bars on the fire resistance also increases.

4. Conclusion

The fire-resistant limit of embedded steel bars is related to the depth of embedded steel bars. With the increase of the depth of embedded steel bars, the fire resistance of reinforced concrete members also increases. The fire-resistant limit of the embedded steel member is related to the thickness of the protective layer. With the increase of the thickness of the protective layer, the fire resistance limit of the rebar planting member also increases. When the protective layer is more than 40 mm, the influence of the depth of the planted steel on the fire resistance of the steel bars is greater than the influence of the protective layer on the fire resistance. Therefore, in actual engineering, the corresponding measures should be taken according to the specific conditions of the test pieces.

Acknowledgments

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