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Remaining Bond Strength of Adhesive Post-installed Rebar of Injection Type After Fire

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Abstract

The experiments of post-installed adhesive anchoring systems of three kinds of injection, epoxy, urethane and in-organic were taken in focusing on bond failure (bond strength) after fire assumed joints between members in long term. The following conclusions were recognized by their experiments.

First remaining bond strengths after fire have different performance depends on kinds of adhesion. Second remaining bond strength of epoxy injection resin type have the same performance of normal temperature in short term up to 275 ℃ after fire and cooling down to air temperature. Third remaining bond strengths after fire decrease in accordance with increase of heated temperature and are approximated by linear straight lines. Forth it is supposed that a test method for evaluating remaining bond strengths after fire assumed joints between members in long term.

Keywords: Adhesive Post-installed Injection Anchors; Fire Resistance; Bond Failure; Bond strength; After Fire

1. INTRODUCTION

Post-installed adhesive anchoring systems are used in important joints between structure members on seismic retrofitting and renewal applications today. Especially post-installed adhesive anchoring systems of 'injection type' are used for a lot of needs of using anchors with low noise and low vibration in seismic retrofitting and renewal while living in buildings[1][2]. However there are a lot of problems that are not clarified when using post-installed adhesive anchors in connections between members in long term. They are creep, influence of environmental temperature and fire resistance, in particular there are few verifications in fire resistance, for example performance of adhesive post-installed anchors during fire and after fire. Additionally it is so important that performance of them after fire are recognised for diagnosis in buildings after damage of fire accidents and maintenance and repair for damaged buildings in fire accidents[3].

There are a few announced papers verified bond strength in post-installed adhesive injection rebars during fire for using them in connections between members in long term[4]. However there are no announced papers verified remaining bond strength in post-installed adhesive injection rebars 'after fire' focusing on diagnosis in buildings after damage of fire accidents and maintenance and repair for damaged buildings after fire accidents.

Therefore experiments of verifications for remaining bond strength after fire are implemented assumed post-installed adhesive injection rebars in long term. The tested adhesive injections are three kinds of adhesions, epoxy resin, urethane resin and in-organic. Finally disccusions and danalyses are showed based on results of the experiments.

2. ADHESIVE POST-INSTALLED ANCHORS USED THIS STUDY

Adhesive Bond in detailed of injection cartridge type of adhesive post-installed anchors are shown in Table1. In this paper three kinds of adhesive bonds, epoxy (A), urethane (B) and in-organic (C) 'cement' in wide-rainging using in Japanese market are referred.

Table1 Material property of adhesive resin used in this study

Material property test	Adhesive materials				
	Epoxy resin (A)		Urethane resin (B)		In-organic (C)
	Resin	Adhesion	Resin	Adhesion	Materials
Main contained component	Bis phenol A, Bis phenol B	Meta-xylene-diamine ＋ Quartz	Urethane ＋ Acrylate	Benzoyl-peroxide	Cement based mortar ＋ Accelerator
σ_c (MPa)	109.0	108.0	139.0	85.6	53.7
σ_t (MPa)	75.7	45.1	25.8	8.5	-
σ_M (MPa)	118.0	66.7	79.9	20.8	-
σ_{st} (MPa)	10.3	7.5	-	5.2	-
$\tau_{a,n}$ (MPa)	25		19		20

Note) σ_c: Compressive strength, σ_t: Tensile strength, σ_M: Bending strength, σ_{st}: Tensile shear bond strength, $\tau_{a,n}$: Bond strength of adhesions

3. TEST SETUP AND RESULTS

3.1 Brief Overview

Specimens' specifications is shown in Fig.1. Specifications of electrical oven and test specimens are shown in Photo1. And strength test results in D16 rebar materials is shown in Table2.

The main parts of the test equipment are Universal testing machine of 1,000 kN in the second laboratory of Katsushika campus in Tokyo University of Science.

Steel column (diameter 150mm, height 300mm and thickness 5mm) filled in concrete (design standard strength F_c=15N/mm^2) used ordinary portland cement is prepared and a hole (diameter 20mm and effective enbedement depth 160mm (10d_a)) is hammer drilled into the concrete, into which the rebar (D16, diameter 16mm (d_a) without cutting at an angle) is inserted and fastened with three kinds of adhesions, epoxy resin (A), urethane resin (B) and in-organic (C) (cement). And the rebar of high strength (SD685, yield strength 685 N/mm^2) are used due to focusing on bond failure. In addition to two thermocouples are installed to measure the temperature in the bond. One of the thermocouples is inserted down to the bottom of the hole and the other is inserted in the position of about 30mm from the top surface in concrete hole into the bond.

Universal oil testing machine and conditions of displacement meters are shown in photo1-4.

And the electrical oven around the specimen is placed and a jig is put on the surface of the concrete in it due to preventing concrete cone failure. The concrete stregth of specimen is 28.4 N/mm^2 in experiments after casting (material age 97 days). The displacement of anchors are measured in average deformations of displacement meter ① and ③ put on a displacement jig to be closed under upper rebar chuck in the testing machine. However the displacement also include strain of rebar.

Failure modes of post-installed adhesive anchors are the flollowing three modes mainly, steel failure, cocnrete cone failure and bond failure[5]. This experiments focusing on performance of bond failure therefore the rebar of the high strength are used due to preventing steel failure mode and the jigs on the surface of concrete in specimens are put due to preventing concrete cone failure mode.

Table2 Strength test results in D16 rebar materials

	Yield strength N/mm^2	Tensile strength N/mm^2
D16（SD685）	708.6	906.2

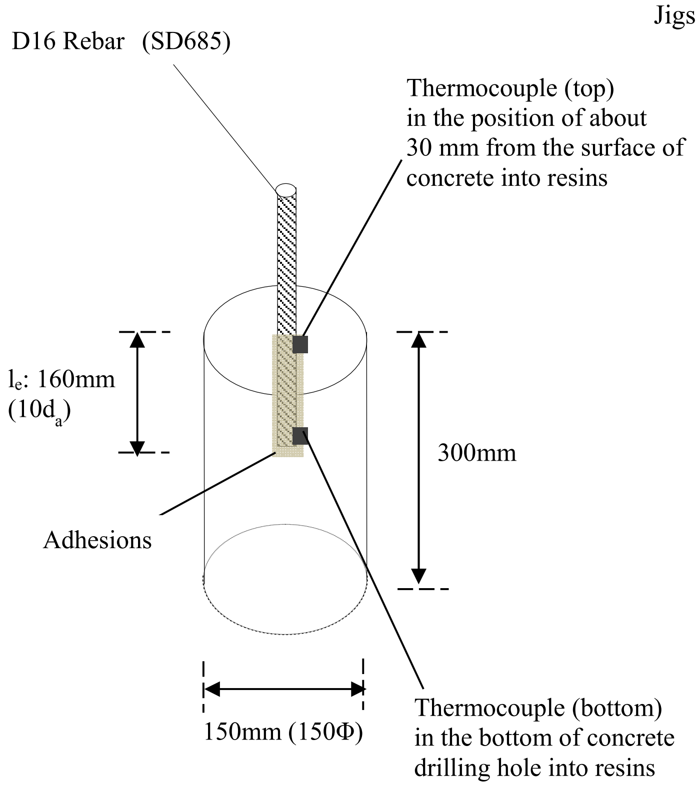

Fig.1 Specimens' specifications

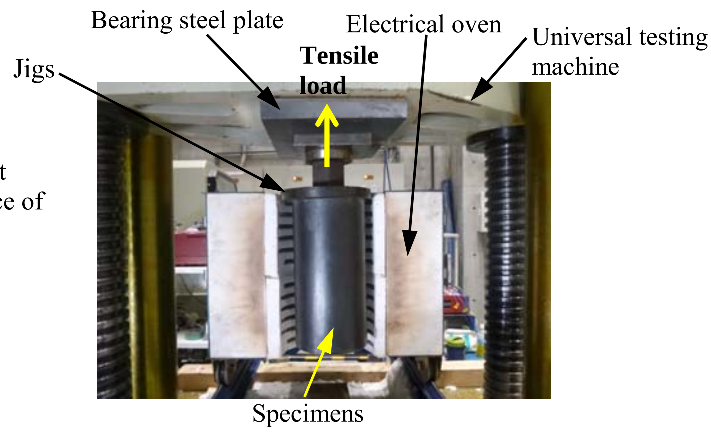

Photo1 Electrical oven and test specimens

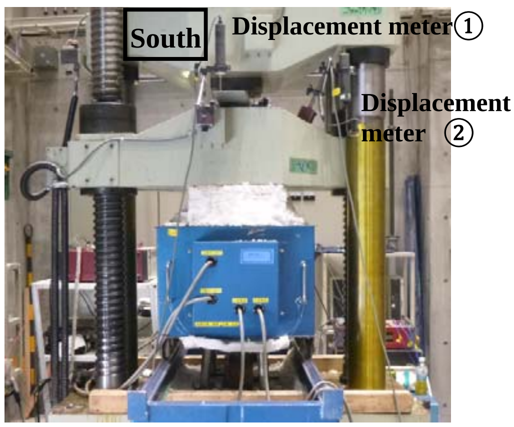

Photo2 Universal oil testing machine

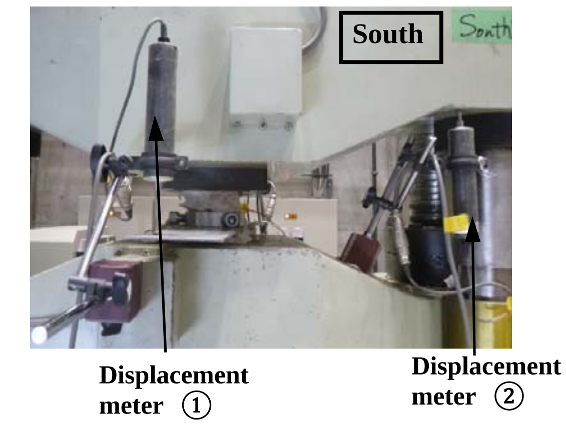

Photo3 Conditions in displacement meters①②

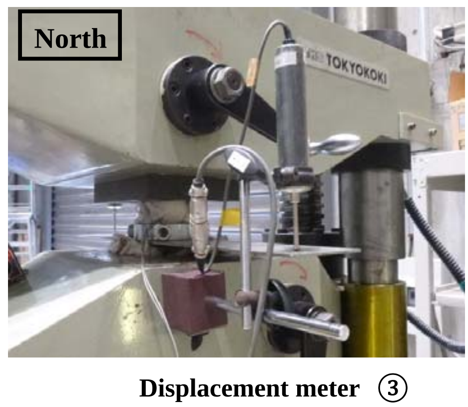

Photo4 Conditions in displacement meters③

3.2 Parameters of Experiment

Conditions of heating and loading in experiments are shown in Fig.2. Conditions of parameters in each specimen are shown in Table3. And the temperature of Fig.1 shows the average of two thermocouples as Fig.1.
The time of heating up to the target temperature varies depending on the target temperature itself and the temperature at which the furnace is set. They are around 0.8 ℃/min in specimens.
Loading and heating are implemented as Fig.2 for the purpose of checking of re-use performance after fire. First of all tensile load is acted and then is heated by each target temperature. The tensile loads are decided in tensile design load in long term calculating based on equations of reference [6]. (The tensile design load is described afterwards.) Second after heating until target temperature cool down to air temperature (less than 20 ℃) keeping in long term tensile loads. Third after returning back to air temperature tensile loads are acted by bond failure.

It is one of examples that seismic load is acted after fire in connections using adhesive post-installed anchors between members in long term. Speed of acting tensile load is about 0.02 kN/mm^2 per second based on a guideline in standard test method of adhesive post-installed anchors in reference [7]. Definition of bond failure is decided in the position of 30 mm in the average of two displacement meters as photo3,4.

Tensile strength of adhesive post-installed anchors in normal temprature is evaluated in strength equations of Japanese seismic retrofitting guideline as reference [5]. The results remaining few tensile bond strength beyond 200 ℃ in temperatura of specimens are reported as reference [4]. And the results of the same ultimate tesile remaing bond stergth in short term until 250 ℃ are reported in the experiments verified remaining tensile bond strength using only epoxy injection adhesive post-installed anchor as reference [8]. Therefore temprature parameters, that is each target temperature as from 150 ℃ to 400 ℃ in every 50℃ set up due to verifying remaining tensile bond stregth after fire considering on different result depends on kinds of adhesions. And additional experiment is implemented in 275 ℃ because there is big defferent remaining bond strength between 250℃ and 300℃. In addition bond failure occured in being acted tensile design load of long term over the target temperatura of 350℃ during implementing the experiment of 350 ℃ of epoxy resin. Therefore no tensile design load is acted in the experiments of 350℃ and 400℃ in the target temperature of epoxy resin. And one more additional expeirment is also implemented in 100℃ of urethane rasin as the target temprature because remaining bond strengths in 150℃ and 200℃ are closed to the bond strength in normal temperature.

3.3 Tensile Loads in Long Term

Tensile loads in long term are calculated based on allowable bond strength of long term and normal temperature in upper side of reinforced concrete beams in Standard for Structural Design of Reinforced Concrete Structures[5] by Architectural Institute of Japan (AIJ) (equation (1)). And the tensile load calculated as the equation (1) are multiplied by remaining ratio of bond strength between rebar and concrete in recorded temperature in guide book for fire-resistive performance of structure materials[9] (equation (2), (3)). The tensile load in long term are shown in Table3. How to calculate design tensile load in long term using bond strength in long term are showed by following below equations based on seismic reirofitting design guidelines[5] and design recommendations for composit constructions[10]. And based on their guidelines allowable bond strength in adhesive post-installed anchors in normal temperaturas is shown by equstion (8).

$$\tau_{cia,l} = (1/15) \cdot F_c \tag{1}$$

$$\tau_{cia,l,r} = \tau_{cia,l} \cdot \delta_r \tag{2}$$

$$T_{a3,l} = \tau_{cia,l,r} \cdot \pi \cdot d_a \cdot l_e \tag{3}$$

$$T_{a3,u} = \tau_a \cdot \pi \cdot d_a \cdot l_e \tag{4}$$

$$\tau_a = T_{a3,u} / (\pi \cdot d_a \cdot l_e) \tag{5}$$

$$\tau_{al} = T_{a3,u} / (3 \cdot \pi \cdot d_a \cdot l_e) \tag{6}$$

$$\tau_{as} = T_{a3,u} \cdot 2 / (3 \cdot \pi \cdot d_a \cdot l_e) \tag{7}$$

$$\tau_{au} = 10 \cdot \sqrt{(\sigma_B/21)} \tag{8}$$

($\tau_{cia,l}$: allowable bond strength in long term N/mm^2, $\tau_{cia,l,r}$: design bond strength in long term N/mm^2, δ_r: Remaining ratio of bond stress, F_c: concrete design standard strength N/mm^2, $T_{a3,l}$: design tensile load in long term N, $T_{a3,u}$: ultimate design tensile load N, τ_a, τ_{au}: bond strength N/mm^2, τ_{al}: allowable bond stregth in long term of normal temperatura N/mm^2, τ_{as}: allowable bond stregth in short term of normal temperatura N/mm^2, d_a: daimeter of rebar mm, l_e: effective embedment length mm, σ_B: concrete strength N/mm^2)

Table3 Specimens' list

No.	Adhesion	During heating (during fire) conditions					
		Target Temperature		$\tau_{cia,l}$	δ_r	Long term tensile (design) load	
		℃	Times min	N/mm^2		$\tau_{cia,l,r}$ N/mm^2	$T_{a3,l}$ kN
①		150	162		0.6	0.6	4.9
②		200	225		0.45	0.45	3.7
③		250	287		0.3	0.3	2.5
④	Epoxy	275	318		0.26	0.26	2.1
⑤		300	350		0.225	0.225	1.9
⑥		350	412		0	0	-
⑦		400	475		0	0	-
⑧		100	100		0.8	0.8	6.5
⑨		150	162		0.6	0.6	4.9
⑩		200	225	1.0	0.45	0.45	3.7
⑪	Urethane	250	287		0.3	0.3	2.5
⑫		300	350		0.225	0.225	1.9
⑬		350	412		0.15	0.15	1.3
⑭		400	475		0.1	0.1	0.9
⑮		150	162		0.6	0.6	4.9
⑯		200	225		0.45	0.45	3.7
⑰		250	287		0.3	0.3	2.5
⑱	In Organic	300	350		0.225	0.225	1.9
⑲		350	412		0.15	0.15	1.3
⑳		400	475		0.1	0.1	0.9

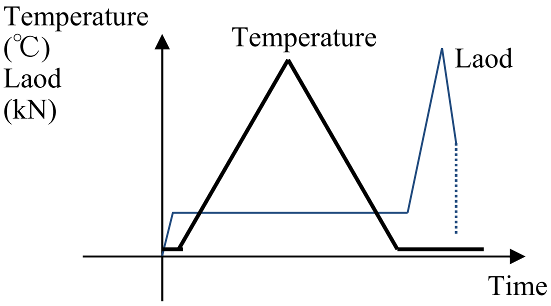

Fig.2 Conditions of heating and loading

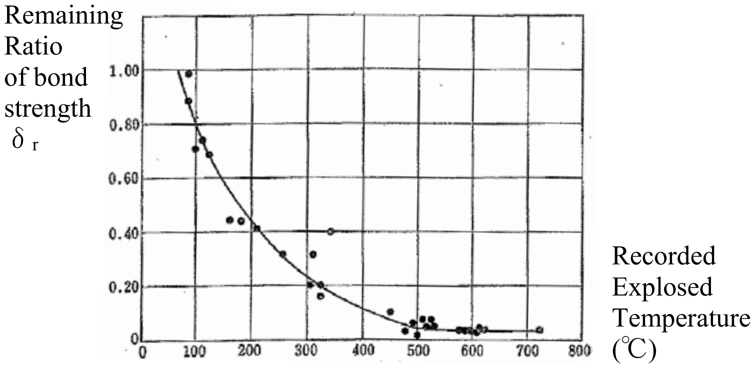

Fig.3 Remaining ratio of bond strength in reinforced concrete[9]

3.4 Results

Results of experiment are shown in Table4. And the behaviour of each specimen after failure are shown in photo 4-6. Relations between time and recorded explosed temperature and relation between time and tensile loads in 300 ℃ of recorded temperature are shown in Fig. 4-5. And then relations between recorded temperature and maximum tensile loads and relationship between recorded temperature and maximum bond strength are shown in Fig. 6-7.

Table4 Results

No	Adhesions	During heating		After heating			Design bond strength	
		Temp.	$T_{a3,l}$	Max. Tensile Load	$\tau_{au,r,e}$	Failure Modes	τ_{au}	τ_{as}
		℃	kN	kN	N/mm^2		N/mm^2	N/mm^2
①	Epoxy	150	4.9	**190.1**	**≧23.6**	**S**	**11.5**	**7.7**
②		200	3.7	**180.0**	**≧22.3**	**S**		
③		250	2.5	**181.9**	**≧22.6**	**S**		
④		275	2.1	**117.5**	**14.6**	**B**		
⑤		300	1.9	**9.6**	**1.1**	**B**		
⑥		350	-	**17.0**	**2.1**	**B**		
⑦		400	-	**9.0**	**1.1**	**B**		
⑧	Urethane	100	6.5	**133.0**	**16.5**	**B**	**11.5**	**7.7**
⑨		150	4.9	**143.0**	**17.7**	**B**		
⑩		200	3.7	**95.5**	**11.8**	**B**		
⑪		250	2.5	**55.5**	**6.9**	**B**		
⑫		300	1.9	**56.6**	**7.0**	**B**		
⑬		350	1.3	**28.8**	**3.5**	**B**		
⑭		400	0.9	**17.8**	**2.2**	**B**		
⑮	In Organic	150	4.9	**78.5**	**9.7**	**B**	**11.5**	**7.7**
⑯		200	3.7	**78.5**	**9.7**	**B**		
⑰		250	2.5	**80.5**	**10.0**	**B**		
⑱		300	1.9	**62.0**	**7.7**	**B**		
⑲		350	1.3	**53.0**	**6.5**	**B**		
⑳		400	0.9	**48.0**	**5.9**	**B**		

Notes) Temp.: Temperature in the average between temperature (top) and temperature (bottom) as the Fig.1

$\tau_{au,r,e}$: Remaining bond strength in experiment

S: Steel failure , B: Bond failure

① ③ ④ ⑤ ⑥ ⑦

Photo4 Pictures of specimens after bond failures (Epoxy ①-⑦)

Notes) ①③: Steel failure

⑨ ⑩ ⑪ ⑫ ⑬ ⑭

Photo5 Pictures of specimens after bond failures (Urethane ⑨-⑭)

⑮ ⑯ ⑰ ⑱ ⑲ ⑳

Photo6 Pictures of specimens after bond failures (In-Organic ⑮-⑳)

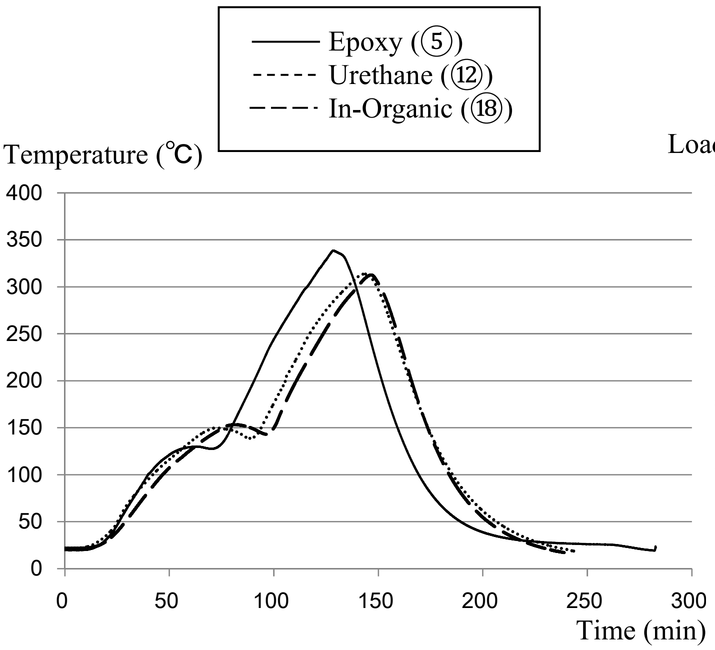

Fig.4 Time-temperature curves in specimens (⑤, ⑫, ⑱)

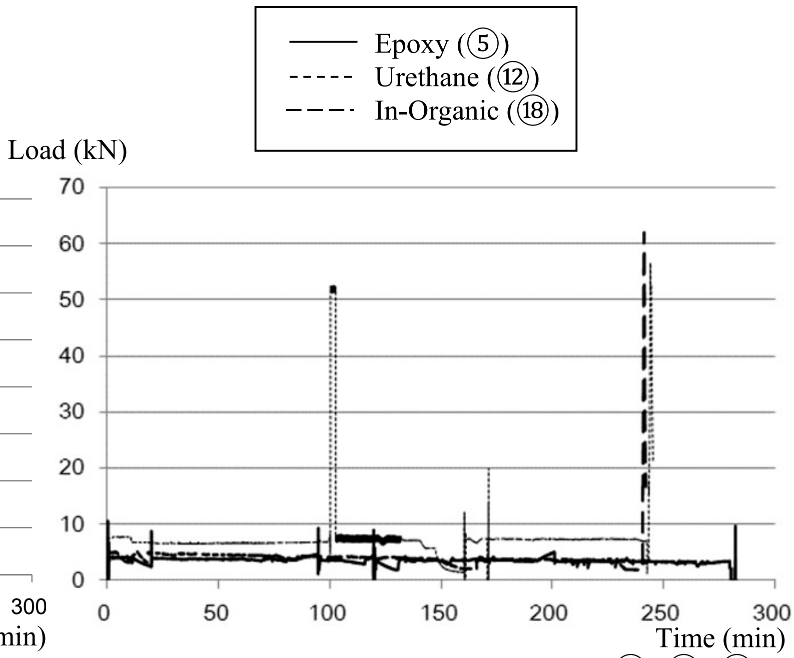

Fig.5 Time-load curves in specimens (⑤, ⑫, ⑱)

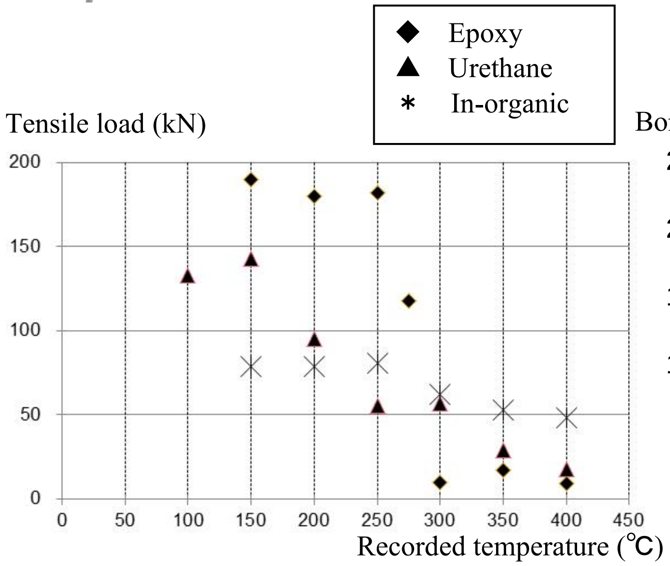

Fig.6 Relation between temperature and maximum tensile loads

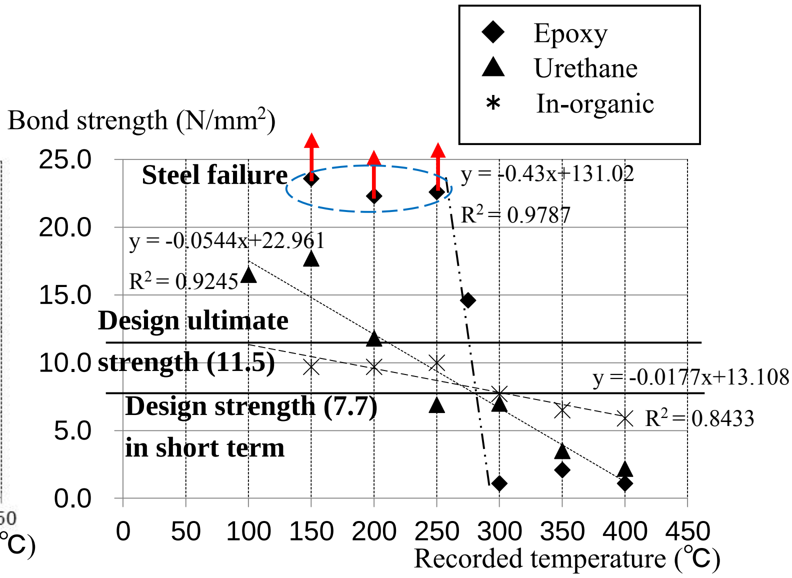

Fig.7 Relation between temperature and maximum bond strength

4. DISCUSSION

Relation between recorded maximum temperature and remaining bond strength in cartridge type of all three adhesive injection post-installed anchors are shown in fig.7. The experiments are taken for confirming re-using of adhesive injection post-installed anchors after fire. And they are assumed that seismic loads and so on in short term are acted after fire in connections acted long term tensile loads between members in long term. In epoxy resin (A) maximum tensile loads are determined in steel failure by 250℃ in recorded maximum temperature. Because the experiments are taken on putting jigs on the surface of concrete specimens and concrete cone failure are prevented the maximum bond stress are more than the maximum tensile loads. Therefore bond strength calculated based on maximum tensile loads meets with ultimate design bond strength. Additionally degradation in epoxy adhesions after cured is advanced from about 250 ℃ [11] and in 275 ℃ failure mode is bond failure however the bond strength in 275 ℃ meets with ultimate design bond strength. And in 300 ℃ remaining bond strength reduce about 1.0 - 2.0 N/mm^2 dramatically. That is to say maximum bond strength are approximated by reducing of a liner straight line from beyond 250 ℃ to less than 300℃.

The remainig bond strength of both urethane and in-organic adhesions are approximated by reducing of a liner straight line in accordance with increase of temprатures as the Fig.7. and urethane adhesions are larger gradient than in-organic in liner straight line. And the bond strength in urethane by beyond 200 ℃ meets with ultimate design bond stregth and then the bond strength in urethane by about 280 ℃ meets with short term design bond strength. On the other hand the bond strength in in-organic by about 90 ℃ meets with ultimate design bond strength and then the bond strength in in-organic by about 300 ℃ meets with short term design bond strength. These results are shown in similar trend [9][12] for the feature of heat in cured urethane adhesions and in remaining compression strength of cement and concrete after explosed heating.

Additionally thinking of fire-resistance design it is so important that design bond stregth of epoxy adhesion (epoxy adhesion (A)) in post-installed adhesive anchors of concrete members is designed not to excceed 275 ℃. And then it is so important that design bond stregth of urethane adhesion (urethane adhesion (B)) in post-installed adhesive anchors of concrete members is designed not to excceed 200 ℃ (in ultimate design bond stregth) - 275 ℃ (in short term design bond strength) and also it is so important that design bond stregth of in-oragnic adhesion (in-organic adhesion (C)) in post-installed adhesive anchors of concrete members is designed not to excceed 100 ℃ (in ultimate design bond stregth) - 300 ℃ (in short term design bond strength).

5. CONCLUSION

In this experiment and study the knowledge of the following below bacame visible for remaining bond strength after fire in three kinds of adhesions (epoxy, urethane and in-organic ‘cement’) of adhesive post-installed anchors of injection type in wide-rainging using in Japanese market.

1) Remaining bond strength after explosed high temperature (after fire) are different depending on kinds of main adhesions.
2) Remaining bond strength of epoxy adhesion in post-installed anchors after explosed high temperature (after fire) has the same design bond strength as normal temperature by 275 ℃ in explosed temperature however after that it decreases dramatically.
3) In urethane and in-organic adhesion remaining bond strength after explosed high temperature (after fire) decrease in accordance with increase of heating temperature and are approximated as a liner straight line.
4) In this study a proposal as the test method is shown for taking experiments in remaining bond strength of post-installed adhesive anchors after explosed high temperature (after fire) assumed connections between members in long term.
5) In fire-resistant designs it is so important that the temperature of post-installed adhesive anchors into members of reinforced concrete is not beyond 275 ℃ of epoxy, 200 ℃ - 275 ℃ of urethane and 100 ℃ - 300 ℃ of in-organic adhesion. And also it need be confirmed that explosed high temperatura of adhesive post-installed anchors into concrete members are not beyond these temperature of the results in this experimnet for re-using of them.

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