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Structural Performance of Steel Pipe Splice for SD500 High-strength Reinforcing Bar under Cyclic Loading

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Abstract

It is the purpose of this study to evaluate the structural performance of steel pipe splice for SD500 high-strength reinforcing bar, through a cyclic loading test. The experimental variables adopted in this study include the development length of rebar, the type of sleeve, and size of reinforcing bar, among others. The results of this study showed that the developed steel pipe splice system for SD500 high-strength reinforcing bar, retained the structural performance required in domestic, ACI and AIJ code. It is considered that the study result presented in this paper can be helpful in developing a reasonable design method for a steel pipe splice system for SD500 high-strength reinforcing bar.

Keywords : SD500 High-strength Reinforcing Bar, Steel Pipe Splice, Structural Performance, Cyclic Loading

1. INTRODUCTION

Of the various reinforcing bar splice methods, the mortar-filled sleeve splice is increasingly being used due to its easy execution and good splicing, even with large-diameter reinforcement. Due to these advantages of mortar-filled sleeve splice, many researchers have experimentally studied the structural performance of this type of rebar splice, to develop the mortar-filled sleeve splice suitable for the demands of construction sites. Among these, A. Einea et al. (1995) conducted monotonic loading tests on steel pipe splice specimens made of small diameter bar (D16, D19), the experimental variables of which included compressive strength of grout, sleeve shapes and others. In that study, structural performances including the confining effect of the sleeve as well as the strength of the grout-filled steel pipe splice were evaluated, and possibilities to apply to construction sites were suggested. Also, L. Lee et al. (1997) executed monotonic loading tests on steel pipe splice specimens made of relatively small-diameter bar (D19, D22, D25), and their experimental variables were sleeve shape, length and diameter of sleeve, and size of reinforcing bar, to examine structural performances mainly in terms of the strength of the steel pipe splice. Additionally, Y. Hayashi et al. (1997) conducted cyclic loading tests on grout-filled coupling steel sleeve splice specimens that were inserted with D35 large diameter bar, for which development length of rebar and compressive strength of grout were selected as experimental variables, to compare and analyze major structural performances such as strength and stiffness of reinforcing bar splice. H. Kim (1998) and H. Kim et al. (2001) executed monotonic and cyclic loading tests on sleeve splice specimens made of D19, D25, D32, D38 bar, the experimental variables of which were compressive strength of charged mortar, development length of reinforcement, size of reinforcing bar, and loading method, to evaluate the structural performances of the rebar splices, including strength, stiffness, slip and others.

On the other hand, both reinforcing bar and concrete have become required to ensure high-strength in designing reinforced concrete members, in line with trend of new buildings being made to be bigger and higher. The sleeve splices developed by major domestic researchers like L. Lee et al. (1997) and H. Kim (1998, 2001) are for SD400 rebar. But, to meet the recent architectural environment, it is urgently demanded to develop the high-strength reinforcement sleeve splice stronger than SD400. In other end, there is the mortar-filled sleeve splice for large reinforcing bar, developed domestically by H. Kim (1998, 2001), which is made from ductile cast iron, but this has the shortcoming of being very expensive compared to other rebar splice methods.

According to the demand and condition of this time, the author's research team (2007) developed a suitable steel pipe sleeve splice for SD500 high-strength bar, using relatively inexpensive steel pipe, and evaluated the structural performance of this splice under monotonic loading. However, before the above sleeve splice for SD500 high-strength reinforcing bar can be practically applied, its structural performance should be confirmed under cyclic as well as monotonic loading.

In this study, we made specimens to actual size by selecting several experimental variables affecting splicing performance of the steel pipe sleeve splice, and executed a cyclic loading test. Following this, we compared and evaluated various aspects of structural performance, including strength, to ensure conformance with ACI (2005), AIJ code (1986) as well as domestic code (2005), and to examine the effects as per those test variables. The goal of this study is to investigate the feasibility of utilizing steel pipe sleeve splice for SD500 high-strength reinforcing bar, based on quantitative engineering data.

2. EXPERIMENT

2.1 Planning and manufacturing of specimens

Sleeve type, development length of reinforcing bar in sleeve, compressive strength of charged mortar, and rebar size were selected as the major experimental variables, and these are described in detail below.

1) Sleeve type (with/without unevenness of sleeve, with/without heat treatment on sleeve material)
2) Development length of reinforcement in sleeve (L_d = 7.5d, L_d = 5d (where d is the nominal diameter of the rebar))
3) Compressive strength of charged mortar (specified compressive strength at 28 days is 75MPa, 95MPa)
4) Size of reinforcing bar (D19, D25, D32, D35)

Eighteen specimens were made, which are presented in Table 1. In this test, a specimen designed to have a development length of 5d was planned to fail finally in bond to examine the bond performance of the bar splice. A specimen having a B2 type smooth sleeve was chosen for this purpose, as B2 type smooth sleeve is a more suitable specimen than one having an A2 type uneven sleeve. Shapes and dimensions of representative specimens are displayed in Figure 1. Details of the two representative types of steel pipe sleeves used in this test are shown in Figures 2 and 3.

The method of charging the specimen with high-strength non-shrink mortar was by pushing mortar into the lower inlet of the sleeve using a pump made exclusively for mortar charging, while the sleeve stood vertically by

Table 1. Summary of specimens

No.	Specimen name	Test variables			
		Rebar size	L_d *1 (d)	Sleeve type*2	f_m *3 (MPa)
1	17A1NC-1	D19	7.5	A1	75
2	17A1HC-1				95
3	27A'1NC-1	D25		A'1	75
4	27A'1HC-1				95
5	27B'1NC-1			B'1	75
6	27B'1NC-3				75
7	27B'1HC-1				95
8	37A2NC-1	D32		A2	75
9	37A2HC-1				95
10	37B2NC-1			B2	75
11	37B2HC-1				95
12	35B2NC-1		5.0		75
13	35B2NC-3				75
14	47A2NC-1	D35	7.5	A2	75
15	47A2HC-1				95
16	47A'2HC-1			A'2	95
17	47B2NC-1			B2	75
18	47B2HC-1				95

(Remark)
*1 : Development length of reinforcing bar
*2 : A1= uneven sleeve, not heat-treated (ϕ60.5)
A'1= uneven sleeve, heat-treated (ϕ60.5)
B'1= smooth sleeve, heat-treated (ϕ60.5)
A2= uneven sleeve, not heat-treated (ϕ76.3)
A'2= uneven sleeve, heat-treated (ϕ76.3)
B2= smooth sleeve, not heat-treated (ϕ76.3)
*3 : Specified compressive strength of charged mortar

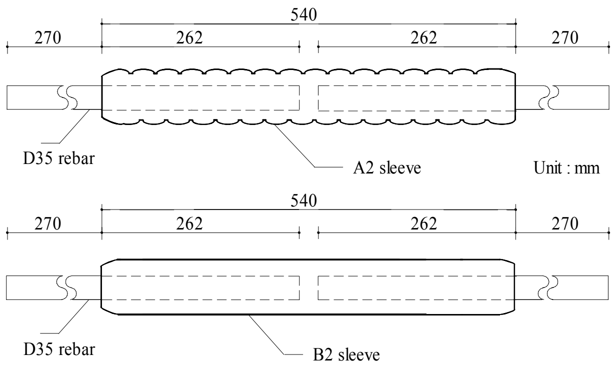


Figure 1. Representative test specimens
(For D35 reinforcing bar, development length=7.5d)

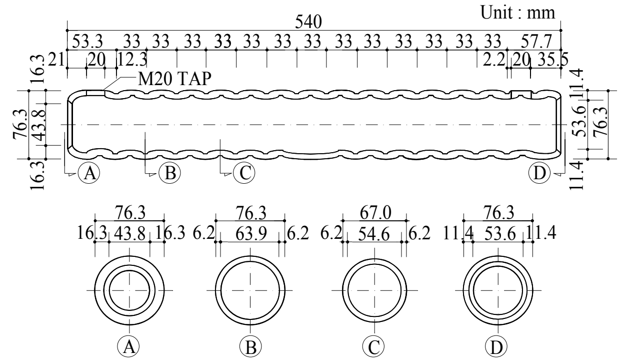


Figure 2. Details of A2 type uneven sleeve

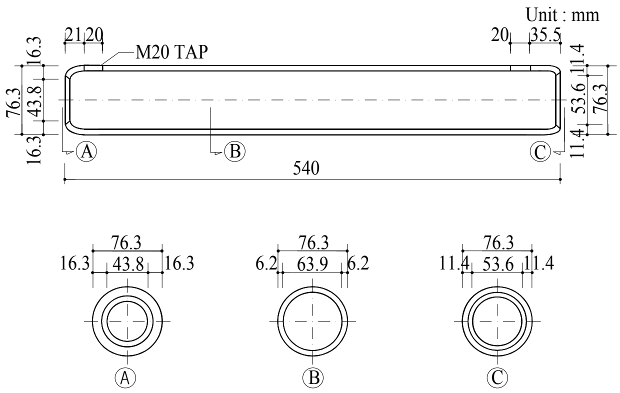


Figure 3. Details of B2 type smooth sleeve

the manufactured anchoring jig, so that the circumstances of charging the sleeve with mortar could be same as on a construction site. The compounding ratio of water and mortar used was 15%.

2.2 Mechanical characteristics of material

The reinforcing bar used in this test was SD500, which has the minimum yield strength of 500MPa, and the test results of tensile strength are presented in Table 2. The stress-strain relationships of D25 and D32 rebars are shown in Figure 4.

There were four kinds of sleeve material used in this experiment. D19 and D25 reinforcement sleeves were used on steel pipes made of STPG 370 for pressure piping with an outer diameter of 60.5mm and a thickness of 5.2mm. And D32 and D35 rebar sleeves were used on steel pipes made of STK 490 partially adjusted chemical component

Table 2. Mechanical properties of reinforcing bar

Rebar size	Yield strength (MPa)	Tensile strength (MPa)	Elongation ratio (%)	Modulus of elasticity (GPa)
D19	590	729	13.9	-
D25	575	689	19.6	199.5
D32	556	696	21.2	201.9
D35	579	753	22.8	-

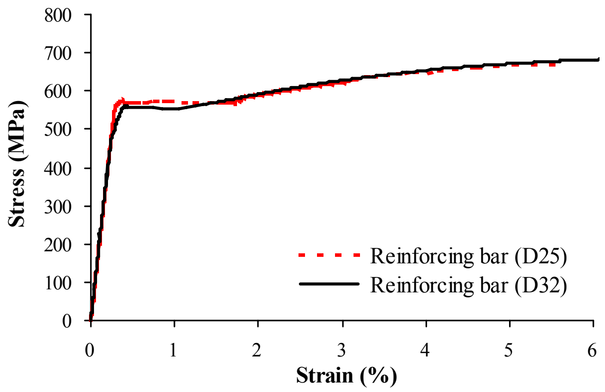


Figure 4. Stress-strain relationship of D25 and D32 bar

Table 3. Mechanical properties of sleeve material

Kinds of steel pipe			Yield strength (MPa)	Tensile strength (MPa)	EL*3 (%)
D_o*1 (mm)	t*2 (mm)	With/out heat treatment			
60.5	5.2	without	361	421	39.0
60.5	5.2	with	306	525	27.5
76.3	6.2	without	478	567	30.0
76.3	6.2	with	464	658	24.0

(Remark) *1 : Outer diameter of steel pipe
*2 : Thickness of steel pipe, *3 : Elongation ratio

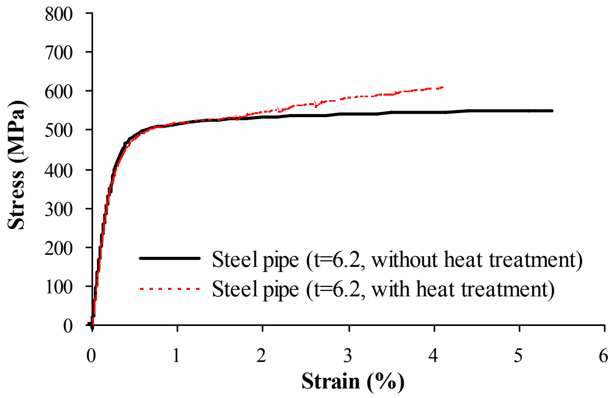


Figure 5. Stress-strain relationship of steel pipe with a thickness of 6.2mm

to improve mechanical property with an outer diameter of 76.3mm and a thickness of 6.2mm. In addition, heat-treated sleeves were also manufactured to improve the mechanical properties of each of the above two types of material. Test results for tensile strength of the four types of material above are presented in Table 3. As the table shows, tensile strengths of heat-treated sleeve material were improved in a range of 16~25%, but the elongation ratios were reduced by 20~30%. The stress-strain relationships of the two representative types of sleeve material are shown in Figure 5.

Table 4. Quality standard of charged mortar

Items \ Mortar kind		N mortar*1	H mortar*2
Time of efflux <J14 flow cone> (Seconds)		10±5	20±5
Setting time (Hours : Minutes)	Initial set	3:30	3:30
	Final set	6:30	6:30
Compressive strength (MPa)	3 days	45	65
	7 days	55	80
	28 days	75	95
Water-cement ratio (%)		15	15

(Remark)
*1 : Existing non-shrink mortar made exclusively for charging sleeve, with a specified compressive strength of 75MPa.
*2 : Non-shrink mortar developed to increase the compressive strength of existing mortar, with a specified compressive strength of 95MPa

Table 5. Compressive strengths of charged mortar

Mortar kind \ Mortar age	3 days (MPa)	7 days (MPa)	The days of testing (MPa)
N mortar	62.0	76.5	83.8
H mortar	69.7	77.2	83.9

Two kinds of high-strength non-shrink mortars were used in this test. The first is an existing product for SD400 reinforcing bar and the other one is a newly developed product for SD500 high-strength reinforcement, which has a higher compressive strength than existing mortar. The quality standards of the two types of charged mortar are shown in Table 4. Somewhat surprisingly, the results of the compressive strength tests did not show a big difference between the existing and the newly developed mortar, as shown in Table 5.

2.3 Loading and measuring methods

This test was performed using the Instron 4495 Universal Testing System. Test specimens were installed and load was exerted, as shown in Figure 6. This equipment can load a maximum of 1,200kN, and apply tensile and compressive force consecutively on a specimen. The strain of the sleeve splice part was measured using 2 Linear variable displacement transducers (LVDTs) installed between measuring devices placed on the reinforcing bar 20mm from each end of the sleeve. In Figure 6, L_o is length of the sleeve, and L is the measured relative displacement length of the sleeve splice developed 20mm from both end of the sleeve.

As indicated in the loading schedule in the AIJ code (1986), cyclic loading was exerted as in Figure 7. Herein, f_y is the specified yield strength of the reinforcement, and ε_y is the yield strain of the specimen. The method to obtain the yield strain ε_y of a specimen are shown in Figure 8.

In this test, following items were measured and recorded in each step.

1) Load exerted on the specimen
2) Relative displacement between measured lengths of displacement of the specimen

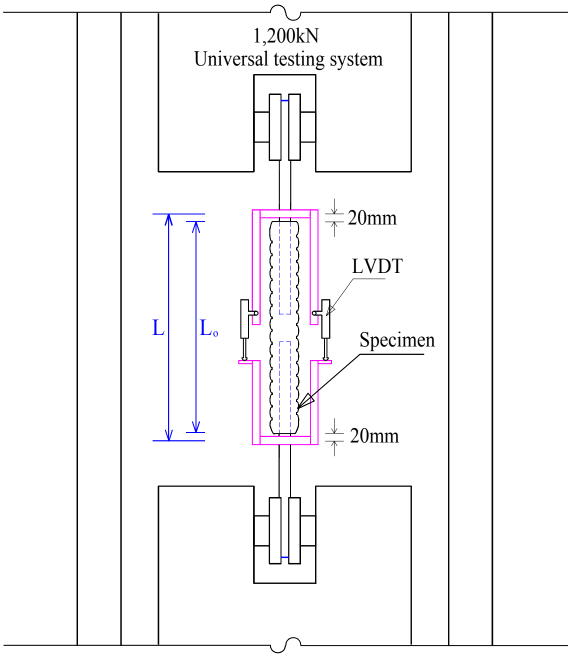


Figure 6. Specimen setup

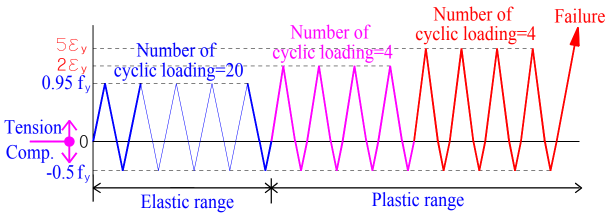


Figure 7. Schedule of cyclic loading

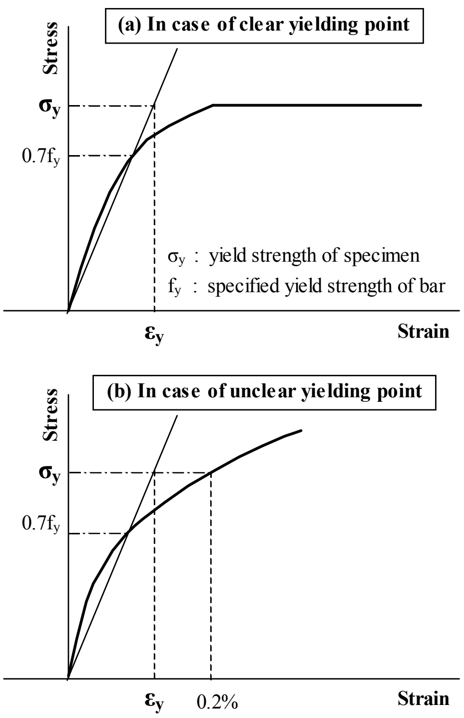


Figure 8. Definition of yield strain ε_y of a specimen

2.4 Test results

Each maximum stress and final failure mode of the eighteen specimens in this study are presented in Table 6, and the stress-strain relationship of representative specimens are presented in Figure 9. Stress(σ) and strain(ε) of the specimens in this figure were obtained as follows.

$$\sigma = P / A_{st} \tag{1}$$

where:
σ = stress of specimen, MPa
P = load exerted on a specimen, N
A_{st} = nominal section areas of bar, mm^2

$$\varepsilon = (\Delta / L) \times 100 \tag{2}$$

where:
ε = strain, %
Δ = increasing distance between measuring lengths of displacements of specimen, mm
L = distances between measuring length of displacements of specimen, mm

As shown in (a), (b) of Figure 9, final failure of the specimens (37A2NC-1, 37A2HC-1) made of D32 reinforcing bar charged with N and H mortar with a rebar development length of 7.5d and A2 type uneven sleeve without heat treatment, was generated by the fracture of reinforcement regardless of mortar type, and maximum strength exceeded minimum tensile strength f_u of rebar. Stiffness of

Table 6. Test results

No.	Name of specimen	Maximum stress (MPa)	Final failure mode*1
1	17A1NC-1	688	B
2	17A1HC-1	721	R
3	27A'1NC-1	617	S
4	27A'1HC-1	625	S
5	27B'1NC-1	671	R
6	27B'1NC-3	677	R
7	27B'1HC-1	680	R
8	37A2NC-1	675	R
9	37A2HC-1	682	R
10	37B2NC-1	678	R
11	37B2HC-1	698	B
12	35B2NC-1	557	B
13	35B2NC-3	509	B
14	47A2NC-1	761	R
15	47A2HC-1	750	R
16	47A'2HC-1	704	S
17	47B2NC-1	736	B
18	47B2HC-1	738	B

(Remark) *1 : R=Fracture of reinforcing bar
S=Fracture of sleeve, B=Bond failure

two specimens showed a gradual decline with increase in load, and a sudden decrease in stiffness was shown from the practical yielding point of reinforcing bar after exceeding the specified yield strength f_y of bar. In addition, although these specimens showed some pinching phenomenon under cyclic loading beyond the elastic range, but displayed enough deformation capacity and reached each maximum strength at strain of 3.8% and 3.6%, respectively, before failure.

As shown in (c) of Figure 9, the final failure of the specimen (37B2NC-1) made of D32 bar and N mortar having a development length of 7.5d and a B2 type smooth sleeve without heat treatment was generated by the fracture of reinforcing bar and a maximum strength was in excess of the minimum tensile strength f_u of rebar. In addition, the stiffness of this specimen showed a gradual decline with increase of load, and this decrease in stiffness appeared to be larger than that of specimen using the A2 type uneven sleeve from the initial stage of loading. Also, while this specimen showed an apparent pinching phenomenon beyond the elastic range under loading, it displayed sufficient deformation capacity and reached maximum strength at a strain of 4.6% before failure.

On the other hand, as shown in (d) of Figure 9, the specimen (35B2NC-1) made of D32 reinforcing bar and N mortar having a rebar development length of 5d and B2 type smooth sleeve without heat treatment, failed finally in bond, and the maximum strength did not exceed minimum tensile strength f_u of rebar. From the loading stage within the elastic range, as load and cyclic numbers were increased, a more severe decrease in stiffness was shown than was the case when the development length was 7.5d, and stiffness decreased more suddenly while showing the unstable behavior of a pinching phenomenon with appar-

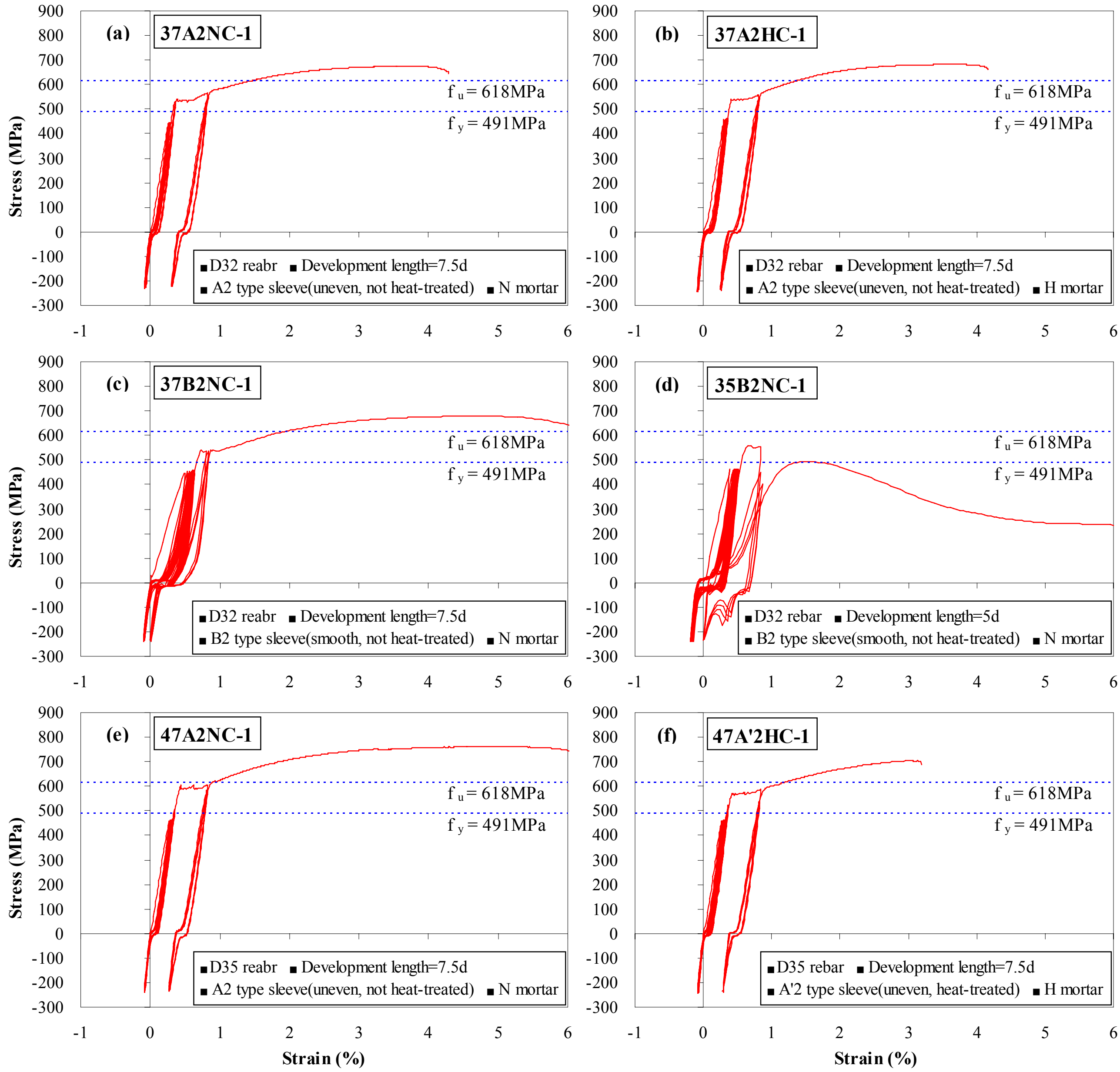


Figure 9. Stress-strain relationship of representative specimens

ent slipping under cyclic loading beyond the elastic range. Bond failure, whereby the reinforcement slipped out of the charged mortar, occurred after this specimen reached maximum strength at a strain of 0.7%.

As shown in (e) of Figure 9, the final failure of the specimen (47A2NC-1) made of D35 rebar and N mortar having a development length of 7.5d and an A2 type uneven sleeve without heat treatment was generated by fracture of the reinforcing bar, which was the same as with specimen 37A2NC-1 [D32 bar, (a) of Figure 9], when all test variables except the rebar size were equal. Also the maximum strength exceeded minimum tensile strength f_u of rebar, and the hysteretic behavior according to the load increase was shown to be similar. This specimen reached maximum strength at a strain of 4.9% before failure.

As shown in (f) of Figure 9, the final failure of specimen (47A'2HC-1) made of D35 reinforcing bar and H mortar having a development length of 7.5d and A' 2 type uneven sleeve with heat treatment was generated by the sudden fracture of the sleeve, but maximum strength exceeded minimum tensile strength f_u of rebar. Its hysteretic behaveior according to the load increase was shown to be similar to that of the specimen (47A2NC-1), which had the same experimental variables except for heat treatment of sleeve and charged mortar, until just prior to sleeve fracture.

The other unquoted twelve specimens showed a similar hysteretic behavior to those of the above six specimens having the same sleeve type and development length of reinforcement, respectively. No special differences were observed between the hysteretic behavior of each of the eighteen specimens as a result of different charged mortar type or rebar size.

3. ANALYSIS OF TEST RESULTS

Based on this test results, effects on tensile strength, stiffness and slip according to the experimental variables were analyzed, and the compliance of structural performance with domestic (2005), ACI (2005) and AIJ (1986) code was examined. However, only tensile strength was examined for specimen 27B'1NC-1, due to a malfunction of LVDTs during the loading. The effects of the development length of reinforcing bar, type of sleeve, rebar size, etc., were analyzed. Herein, all test variables with the exception of mortar type, which appeared to be almost irrelevant to the experiment results, were compared and analyzed.

3.1 Tensile strength

Mechanical splice of reinforced concrete members should develop at least 125 percent of the specified yield strength f_y of reinforcing bar in ACI and domestic code. On the other hand, the AIJ code defines that mechanical splice of reinforced concrete members should endure more than 135 percent of the specified yield strength f_y of rebar, or more than minimum tensile strength f_u of reinforcing bar at the upper three classes (SA, A, B), among sorted performances of splice by four classes.

Tensile strengths were compared according to the major test variables in Figures 10～13.

Tensile strengths were compared according to reinforcement size to examine the effect of that in Figure 10. Here, the experiment data were sorted into two categories according to sleeve type. Tensile strength appeared to be larger in the order of D25, D32, D19, D35 when using an

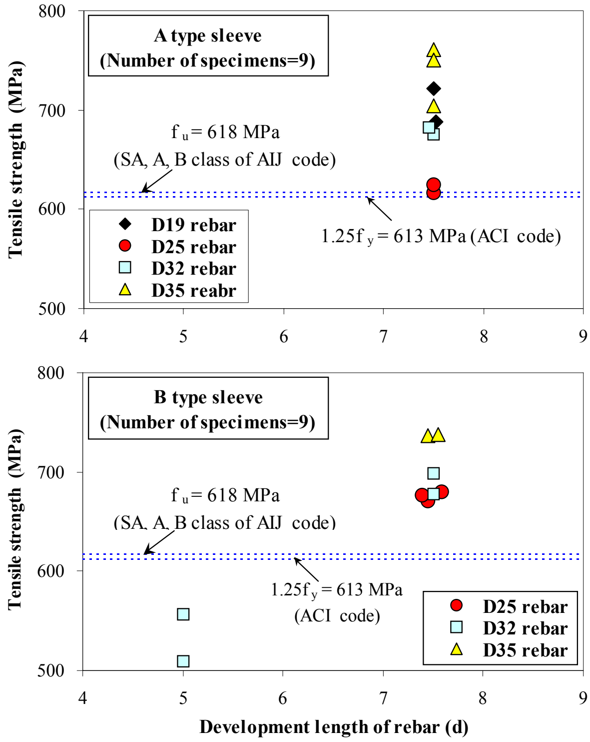


Figure 10. Comparison of tensile strength (rebar size)

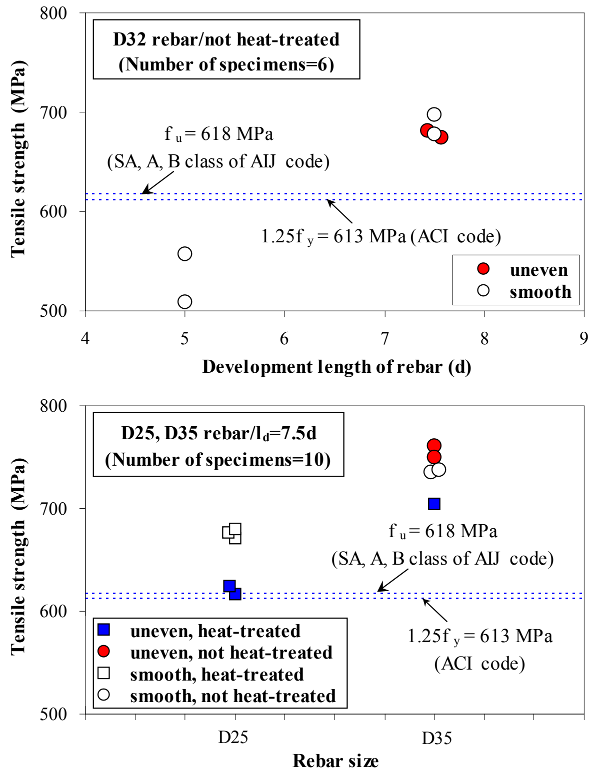


Figure 11. Comparison of tensile strength (sleeve type)

A type sleeve with a development length of 7.5d, as in the experimental study (H. Kim et al., 2007) of monotonic loading, and the same results were shown when using the B type sleeve. It seems not because of the difference in the tensile strength of each steel pipe sleeve splice according to the size of reinforcement, but because of the difference in the tensile strength of the reinforcing bar itself according to the bar size generated in the production process of the bars, as shown in Table 2. On the other hand, the results of the experiment showed that tensile strength increased as the development length of reinforcement increased, when development length were 7.5d and 5d, and D32 rebar was inserted into a B type sleeve.

Tensile strengths were compared according to sleeve type to examine the effect of that in Figure 11. In sleeves without heat treatment, hardly any difference in tensile strength could be observed between each specimen in which D32 reinforcing bar (which has a relatively lower tensile strength than bar of other diameters) had been inserted, regardless of unevenness, but uneven specimens in which D35 rebar (which has a relatively high tensile strength) had been inserted appeared to have a 2~3% higher tensile strength than smooth specimens due to their failure mode. On the other hand, in heat-treated sleeves, uneven sleeve specimens showed a lower tensile strength than smooth sleeve specimens. It seems because the elongation ratio of uneven part of sleeve became low due to the heat treatment of the uneven sleeve that already had the plastic deformation and stress concentration in the production process of unevenness on it and consequently the weakened uneven part of sleeve was fractured first before the fracture of rebar.

Tensile strengths were compared according to final failure mode to examine the effect of that on the specimens shown in Figure 12. Hardly any difference in tensile strength according to final failure mode regardless of unevenness could be observed between each specimen using A and B type sleeves without heat treatment inserted D32 bar. This is because while bond failure occurred in specimen using B type smooth sleeve with D32 reinforcing bar (which has a relatively lower tensile strength than rebar of other diameters), the tensile strength of this specimen almost reached the fracture strength of the spliced reinforcement. In case that the uneven sleeves with heat treatment were used in the specimens made of D25 and D35 bar, the sleeve would be fractured before the reinforcing bar, which means that the tensile strengths of uneven specimens with heat treatment were lower than those of smooth specimens with heat treatment, or those of specimens without heat treatment.

Figure 13 shows a comparison of the tensile strength of all specimens according to a development length of rebar. As you can see in Figure 13, the tensile strengths of the two specimens that used reinforcement with a development length of 5d were less than those of the ACI code and the upper three class (SA, A, B) of the AIJ code. But all sixteen specimens with a development length of 7.5d endured a tensile strength more than 1.25 times the specified

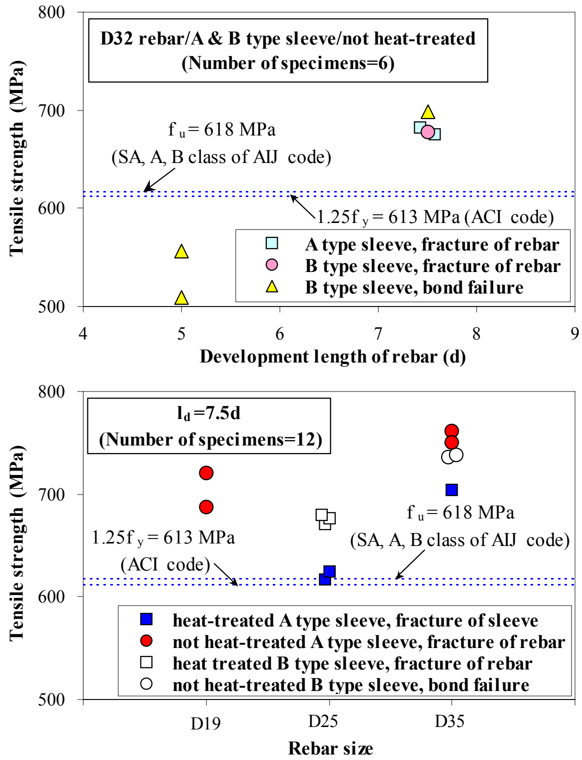


Figure 12. Comparison of tensile strength (final failure mode)

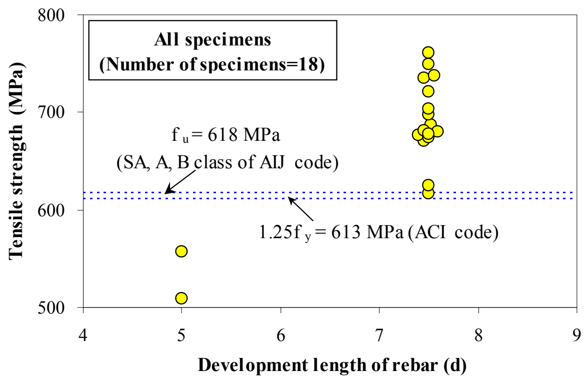


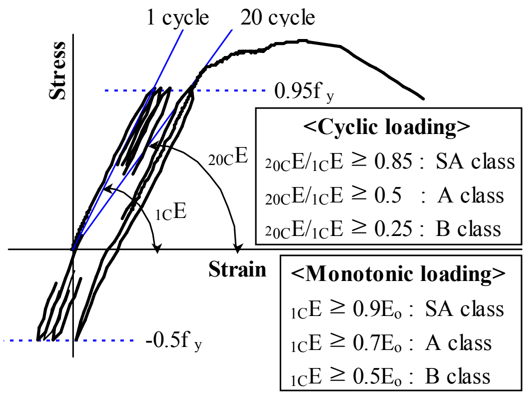
Figure 13. Comparison of tensile strength (all specimens)

yield strength f_y of rebar to satisfy the ACI code. In addition, all sixteen specimens with a rebar development length of 7.5d endured a tensile strength that was more than the minimum tensile strength f_u of reinforcing bar, to satisfy the upper three class (SA, A, B) of the AIJ code.

3.2 Stiffness

There are no provisions regarding the stiffness of mechanical splice of reinforced concrete members in the ACI code. However the AIJ code classifies stiffness under cyclic loading in three classes and defines stiffness differently according to structural design method or position of splice. A definition of stiffness under cyclic loading according to the AIJ code is shown in Figure 14. In addition, a definition of stiffness for monotonic loading is shown together in Figure 14.

Stiffness of first cycle (hereunder, ${}_{1c}E$) and ratio (hereunder, ${}_{20c}E/{}_{1c}E$) of the stiffness in the 20^{th} cycle to that in the first cycle under cyclic loading were compared accord-



※ E_o is elastic modulus of rebar in specimen.

Figure 14. Definition of stiffness (AIJ code)

ing to the development length of reinforcing bar, sleeve type, and rebar size in Figure 15.

As can be seen in (a) and (b) of Figure 15, in the case of specimens made of D32 rebar having a development length of 7.5d, no heat treatment, and an uneven sleeve, ${}_{1c}E$ and ${}_{20c}E/{}_{1c}E$ showed a SA class of structural performance of AIJ code. And ${}_{1c}E$ of specimens having a smooth sleeve showed 50~60% stiffness of uneven cases to meet B class and ${}_{20c}E/{}_{1c}E$ was A class in the structural performance, slightly below SA class. On the other hand, for specimens made of D32 bar that have a rebar development length of 5d and a smooth sleeve without the heat treatment, when compared with specimens of the same conditions but a development length of 7.5d, ${}_{1c}E$ appeared 6% less, to get close to B class, and ${}_{20c}E/{}_{1c}E$ was also shown to be 7% less, to get in A class, presenting some effect by the development length of reinforcement.

As shown in (c) and (d) of Figure 15, ${}_{1c}E$ and ${}_{20c}E/{}_{1c}E$ of specimens made of D35 rebar having a development length of 7.5d and an uneven sleeve showed a structural performance of A class less than the SA class of the AIJ code. In addition, the ${}_{1c}E$ of a heat-treated specimen on the sleeve appeared to be slightly larger than that of one without heat treatment, but the ${}_{20c}E/{}_{1c}E$ appeared to be smaller. It seems because, as mentioned above, while the number of cyclic loadings got increased on the uneven part of sleeve that already had the plastic deformation and stress concentration on it and was more weakened by the heat treatment, the deformation increased more and the total stiffness of sleeve splice became lower. Also, ${}_{1c}E$ and ${}_{20c}E/{}_{1c}E$ of specimens made of D35 rebar with a development length of 7.5d and a smooth sleeve and no heat treatment appeared to be similar to that of a specimen made of D32 bar. In addition, the stiffness of specimens made of D19 rebar with a development length of 7.5d and an uneven sleeve without the heat treatment was similar to that of the specimens made of D32 and D35 under the same conditions, but the ${}_{20c}E/{}_{1c}E$, which is a reduction ratio of stiffness by cyclic loading, appeared to be slightly less.

On the other hand, the stiffness of the specimens made of D25 rebar having a heat-treated sleeve at the first cycle under cyclic loading was relatively small, because the sleeve itself had already been entering the plastic range at first cycle as there is no room in the sleeve section to compare with specimens of other rebar size, and stiffness re-

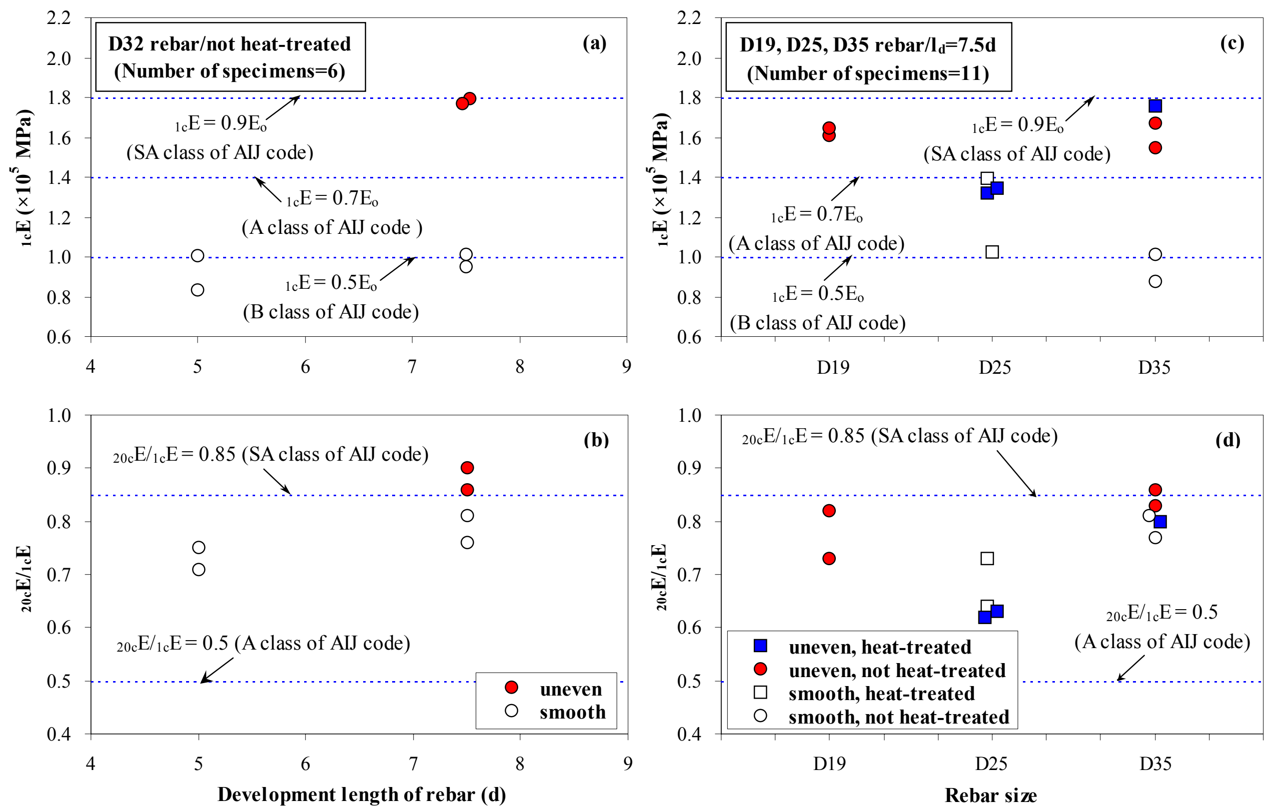


Figure 15. Comparison of stiffness

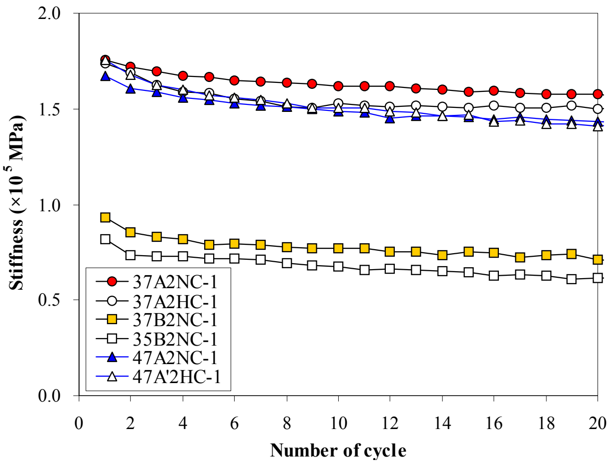


Figure 16. Stiffness change trend of representative specimens by cyclic loading

duction due to cyclic loading appeared to be relatively large. Particularly the stiffness reduction of the uneven specimens appeared larger due to a structural defect of the sleeve itself, when compared with smooth specimens as quoted in the tensile strength section.

The stiffness change trend within the elastic range according to cyclic numbers of loading on representative specimens is shown in Figure 16. The stiffness of all six representative specimens was inclined to decrease slowly according to the increase of cyclic numbers of loading, without special difference according to sleeve type, length of reinforcing bar and kind of mortar. However, it can be confirmed that the stiffness of two specimens (37B2NC-1, 35B2NC-1) made of D32 rebar using B2 type smooth sleeve without heat treatment appeared, when compared with specimens using A2 type uneven sleeve, to be relatively low from the initial stage of cyclic loading.

3.3 Slip

There are no provisions regarding the slip of mechanical splice of reinforced concrete members in the ACI code, however the AIJ code classifies slips under cyclic loading into two classes, and defines them differently according to structural design method or position of splice. The definition of slip under cyclic loading according to the AIJ code is shown in Figures 17 and 18.

Slips in elastic range were compared in (a) of Figure 19. First, it can be observed that when D32 reinforcing bar

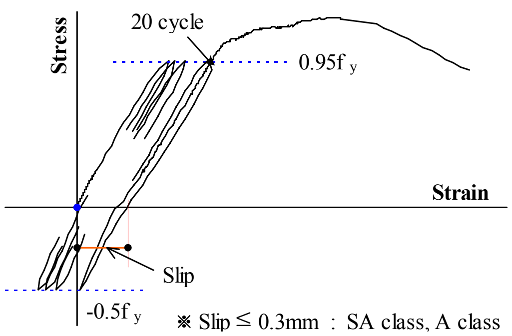


Figure 17. Definition of slip in elastic range (AIJ code)

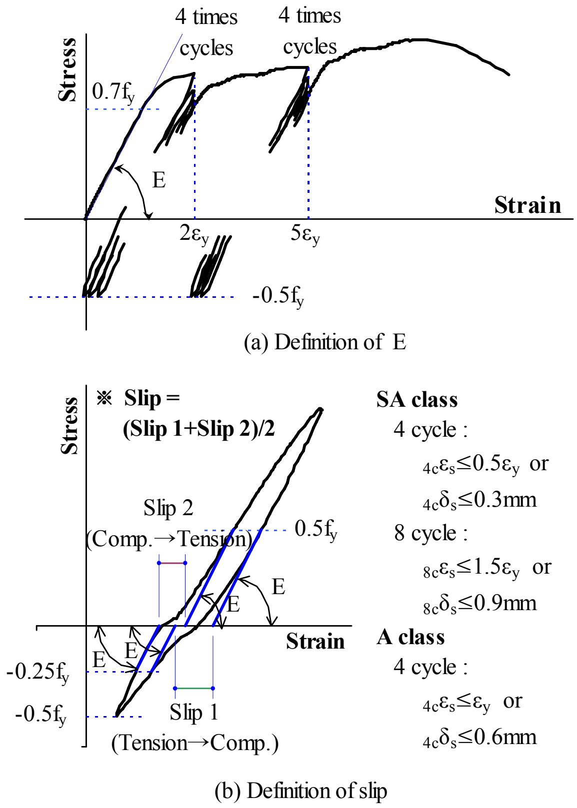


Figure 18. Definition of slip in plastic range (AIJ code)

was inserted to a B type sleeve, the slip decreased as the rebar development length became longer. Slips of specimens made of D32 and D35 bar using an A type uneven sleeve were 70% lower than those of smooth sleeve specimens. However, in case of D25 rebar specimens with a heat treated sleeves and with relatively less room in the sleeve section when compared with other specimens with other size of rebar, at the stage that 95% tensile strength of the specified yield strength of rebar was applied to the specimens, the sleeve already entered the plastic range. So, even after the tensile loads were removed, the slip amounts in elastic range, i.e., residual deformation quantity, were greater than those with other size of rebar. In particular, slips in the elastic range of specimens having an uneven sleeve were shown to be relatively larger than those of one having smooth sleeve, due to plastic deformation and stress concentration of the uneven part, as stated above. On the other hand, when comparing the slips of specimens made from D19, D32, D35 reinforcing bar, differences due to rebar size could not be observed, with the exception of D25 bar which did not have enough room in the sleeve section. In addition, the slips of nine uneven sleeve specimens were approximately 2 times of 0.3mm which is the criteria of the A class of the AIJ code.

Slips of 2 ε_y and 5 ε_y in plastic range were compared in (b), (c) of Figure 19. Just as with elastic range, the longer the development length of reinforcing bar, the lower the slip, and the effect of the rebar development length appeared to become more substantial as the plastic degree grew. Slips of specimens made of D25, D32, D35 rebar using A type uneven sleeve were 50% lower than those

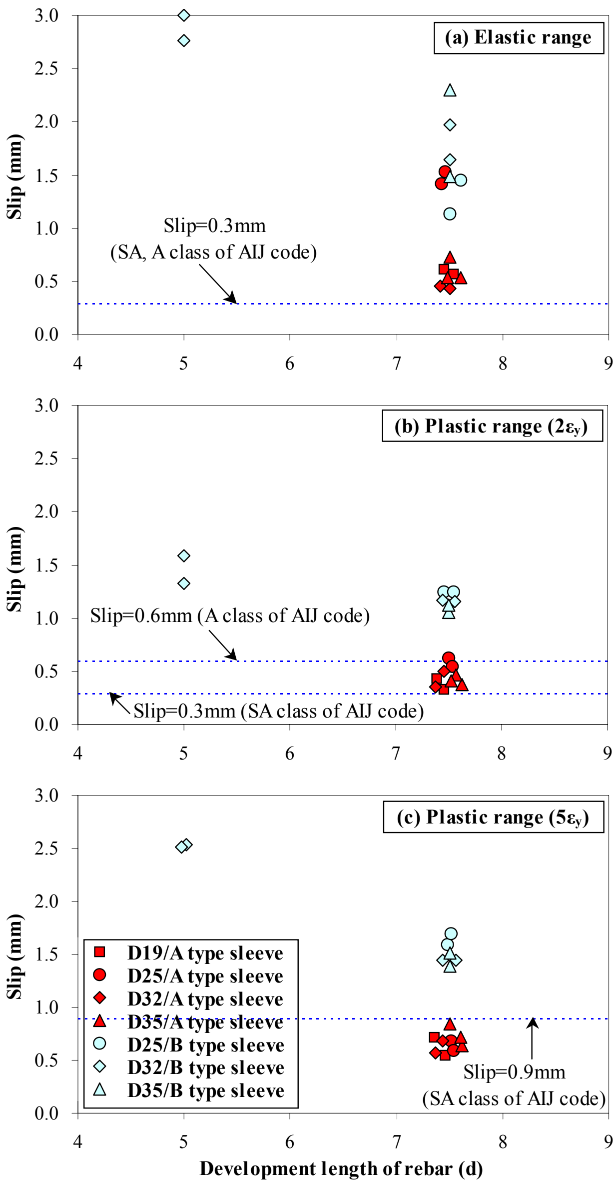


Figure 19. Comparison of slip

with smooth sleeve. Comparing the slips within the plastic range of specimens made of D19, D25, D32, D35 reinforcing bar according to the rebar size, differences did not appear. Herein, the slips within the plastic range of specimens using D25 reinforcement did not show a critical difference from those using the rebar of other size. Even in specimens made of D25 bar, although the sleeve itself had come to a plastic range due to a lack of sectional area to enlarge the slip of elastic range which was the residual deformation quantity, but because that unevenness of the sleeve contributed to bond between the sleeve and the charged mortar, the total slips were shown to be nearly equal to that of the uneven sleeve specimens made of rebar of other size. This is because the slips in plastic range have a closer relation to the bond between rebar and charged mortar and between sleeve and charged mortar while specimens endure cyclic loading.

On the other hand, slips of all specimens, except for one having an uneven sleeve in plastic range 2 ε_y, were below

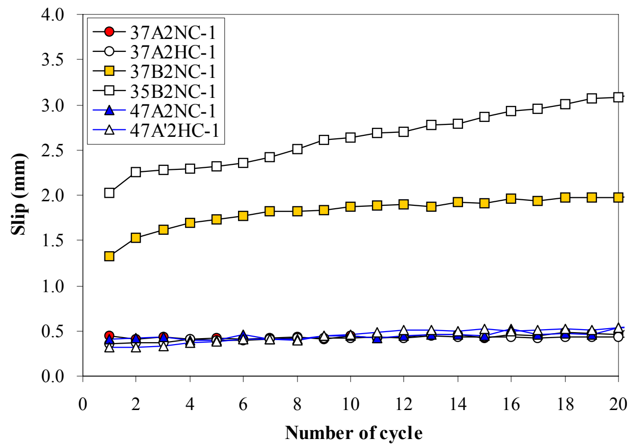


Figure 20. Change trend of elastic slip by cyclic loading on representative specimens

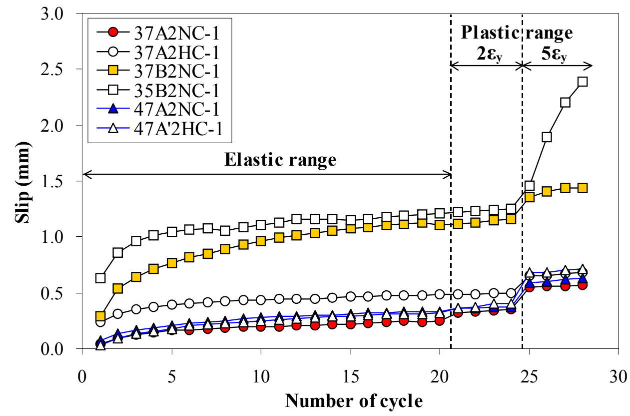


Figure 21. Change trend of plastic slip by cyclic loading on representative specimens

0.6mm and thus met the A class of structural performance according to the AIJ code. However, slips of specimens having a smooth sleeve exceeded 0.6mm, and therefore did not satisfy the A class of structural performance according to the AIJ code. In plastic range 5 ε_y, slips of specimens having an uneven sleeve were below 0.9mm, thus meeting the SA class of structural performance according to the AIJ code, but those of all specimens having a smooth sleeve exceeded 0.9mm, and therefore did not satisfy the SA class of structural performance according to the AIJ code.

The change trend of elastic slip according to the cyclic loading of representative specimens is shown in Figure 20. The elastic slips of specimens with B type smooth sleeve made of D32 rebar appeared to be larger than those of specimens with A type uneven sleeve from the initial stage of cyclic loading. The increase ratio of the slip became larger in correspondence with an increase of cyclic numbers of loading; especially in case of specimen (35B2NC-1) with a short rebar development length, the slip increased a lot more than that of the specimen (37B2NC-1) with a long development length of reinforcing bar, according to the increase in the cyclic numbers of loading. In the four specimens of D32 and D35 bar with A type uneven sleeve, the size of rebar and the kind of mortar seemed to have very little effect on cyclic numbers of loading on elastic slip.

The changing trend of plastic slip according to the cyclic loadings for representative specimens is shown in Figure 21. The plastic slips of specimens with D32 reinforcement and B type smooth sleeve were larger than those of specimens with A type uneven sleeve from the initial stage of cyclic loadings. As the cyclic number of loadings increased, the increasing ratio of slip also appeared greater. Especially, in case of specimen (35B2NC-1) with short rebar development, the plastic slip increased far more rapidly from plastic range since 5 ε_y, than that of the specimen (37B2NC-1) with long development length of reinforcing bar according to an increase in the cyclic number of loadings. Just like the case of elastic slip, the plastic slip of each specimen according to rebar size and mortar type was almost same regardless of cyclic number of loadings.

4. CONCLUSIONS

In this study, we made eighteen actual size specimens of steel pipe splice developed for SD500 high-strength reinforcing bar, and we executed a cyclic loading experiment on these specimens.

We then analyzed effects on structural performance as per experimental variables, including strength, and compared and evaluated these based on domestic and other major code to reach the following conclusion.

1) If reinforcing bar with a development length of more than 7.5d and non-shrink mortar with a specified compressive strength of more than 75MPa at the 28 days is used, the steel pipe splice developed for SD500 high-strength reinforcing bar in cyclic loading will satisfy structural performance of domestic and ACI code, and will have structural performance of higher than “A” class, with the exception of slip in elastic range, even under AIJ code.

2) If reinforcement with a development length of 5d and non-shrink mortar with a specified compressive strength of more than 75MPa at the 28 days is used, the maximum strength of the specimen with a developed steel pipe sleeve will exceed the specified yield strength for rebar, but other aspects of its structural performance will not satisfy domestic and ACI code, or the upper three class of the AIJ code.

3) The shape and manufacturing method of steel pipe sleeve affects the structural performance of steel pipe splice. In particular, unevenness of steel pipe sleeve improves structural performance of sleeve reinforcing bar splice in stiffness and slip. However, if an uneven sleeve is heat-treated to improve the tensile strength of the sleeve itself, its structural performance will be reduced, as sleeve fractures may occur in an uneven part of the sleeve.

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