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EVALUATION OF MECHANICAL PERFORMANCE OF NEWLY DEVELOPED UP-SET COUPLER

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ABSTRACT: *As the size of structures become super larger in the current construction trends, construction engineers have tried to enhance the quality of reinforced concrete structures, the simplification of field works and reduction of construction period. Connection of reinforcing rebar for concrete structures is also an important issue for super sized structures. Most common rebar connection methods available are the lap splice joint, pressure welded joint, and the mechanical joint methods. When thick rebar's are required to be connected, however, design codes such as ACI-318 recommends the lap splice joint to be avoided. This is because of potential difficulties in placing concrete in complex rebar area and securing sufficient cover depth, and uncertainty of bond between rebar and concrete. The welded pressure joint method has some inherent shortcomings in quality control by heating rebar ends and pressure welding them together.*

This study compares the mechanical performance of various connection methods, such as, screw connection methods, which is commonly used for PSC and RC structures, and up-set coupler method, which is recently developed method. From the tensile strength test results, both coupling methods showed even greater tensile strength comparing to the continuous rebar of the same size and in some cases, the up-set coupler showed even better performance. It can be concluded that as the super sized structure increases, the up-set coupler method is a good candidate methods for the connection of steel rebar because of its good mechanical performance and constructability.

KEYWORDS: Rebar coupling method, Lap splice joint, Screw coupler, Up-set coupler, Tensile strength, Yield strength

1. INTRODUCTION

With recent trends of building structures becoming large and high-rise, it is necessary to ensure high quality, streamline the field work process, and shorten the construction period. However, 8m or 10m steel rebar may not meet the required span strength. Thus, pre-assembly of steel rebar and complex methods are positively recommended [Fig 1.], and research into the methods of joining steel rebar is conducted when the same methods are applied. Steel rebar joining methods that are currently applied to concrete structures include lap joining, pressure welding joining, and mechanical joining, and generally, the lap joining method is mainly used in the construction frontlines. The lap joining method involves using the bond stress of a steel rebar lap joint and concrete to transmit stress. Also, the length of steel rebar lap-joining should be big enough to transmit strain, and the lap joining method does not require specialists, and can be conducted through the assembly of steel rebar. However, if concrete strength and its covering thickness are not sufficient, the method may cause the problems of concrete cracks, and the unduly long construction period and excessive costs. As shown in Fig. 1, the clustered steel rebar arrangement may cause faulty concrete placing, weakening of structures' durability, and low workability according to joint location. As such, since the steel rebar lap joining may cause problems, the current concrete structure design criteria (2003) and ACI Committee 18 Structural Building Code regulate the use of lap joining in steel rebar and deformed rebar with a radius above appropriate levels.

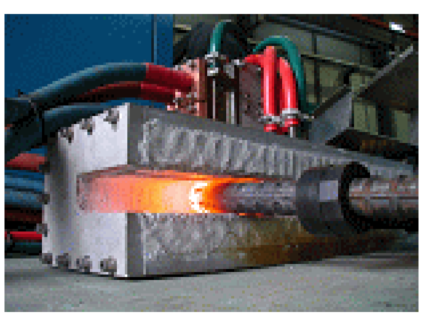
Therefore, in order to fundamentally address the problem of low workability, to boost workability, and to cut the construction period and materials costs, this paper examines a new-concept up-set coupler designed to reduce steel rebar clustering, and to improve workability by comparing it with existing steel rebar joining methods, thus verifying its mechanical and structural performances. With regard to the up-set coupler which mechanically joins the physically strained steel rebar section by diameter this paper conducts tensile tests by diameter according to couplers such as the screw coupler, conventional steel rebar and up-set coupler which are used for the comparative analysis of mechanical properties of joints. Also, the paper determines whether or not a tensile strength above the levels prescribed in ISO (International Organization for Standardization) is created, and compares the performances, thus providing basic data for efficient construction work

Fig 1. Steel rebar lap joining

2. UP-SET COUPLER STEEL REBAR COUPLING SYSTEM

2.1. Outline of UP-Set Coupler Steel Rebar Coupling System

The up-set coupler is an steel rebar joining method by which as shown in Fig. 2, the steel rebar cross-section is preheated to about 550□, the preheated section is pressed with a pressure of 15MPa in a certain frame (mold) with a press to mold a shape (Fig. 3), and it is joined using the coupler.



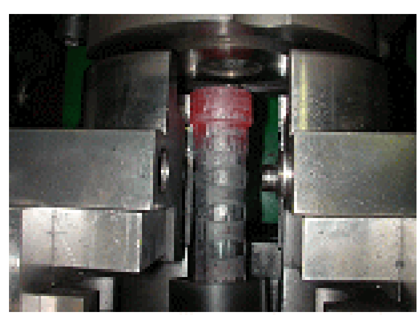


Fig. 2. Preheating the steel rebar section Fig. 3. Molding the preheated section

Compared with the existing (section) screw joining method, i.e., the method of coupling the base steel rebar and the coupler female and male screws which finally rotates the steel rebar to achieve coupling, the up-set coupler does not couples the base steel rebar and coupler, but only couples couplers to connect with the base steel rebar, making it a new-concept steel rebar joining method (Fig 4.). Compared with existing coupling methods, this method does not move the steel rebar, but uses only couplers to couple, thus making coupling speedy and enabling an easy coupling of steel rebar with a large diameter Fig 5. and Fig 6. Show shapes in the molding area and the assembly area, and specifications of manufacturing and assembling molding areas by diameter are shown in Table 1.

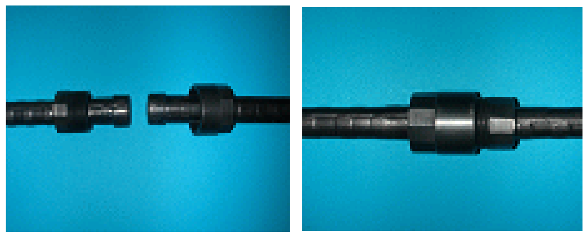


Fig 4. Up-set Coupler

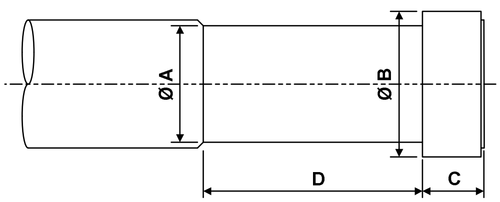


Fig 5. Shape of the coupler's compression area

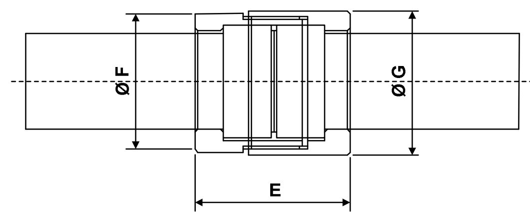


Fig 6. Shape of the coupled coupler

Table 1. Up-Set Coupler Specifications (unit : mm)

Bar No.	A	B	C	D	E	F	G
D13	13	16	8	150	24	22.4	22.5
D16	16.5	19.8	10	154	30	27.6	31.3
D19	19.5	23.5	12	158	36	32.9	37.4
D22	23	27.2	14	160	42	37.9	42.3
D25	26	30.8	16	164	18	41.9	47.9
D29	29.5	34.7	18	168	54	47.1	53.7
D32	32.5	39	20	170	60	52.2	59.4
D35	36	43.2	22	174	66	57.4	66.5
D40	39.5	47.4	24	176	72	62.7	72.7
D41	42.5	50.7	25	182	78	67.1	77.9
D51	52.5	62.5	30	190	92	83	95.9

A: Specimen's nominal diameter
B: Inside diameter of molded section
C: Thickness of molded section
D: Processed compression area
E: Total length of coupled couple
F: Inside diameter of coupled couple
G: Outside diameter of coupled couple

3. TENSILE TEST OF STEEL REBAR JOINING SYSTEM

3.1 Test Outline

Using SD400 prescribed in the ISO, this paper measures the tensile strength according to steel rebar joining methods. Specimens are manufactured and tested using mechanical joining methods including the up-set coupler and the section screw coupler, and conventional steel rebar. Steel rebar used herein are ISO 6935 steel rebar for reinforced concrete, and they have yield strength of over 400Mpa and a tensile strength of over 560Mpa.

3.2 Experimental Variables

Determined as experimental variables for performance evaluation are screw couplers, up-set couplers proposed here in, and conventional steel rebar. Experiments are targeted at eleven types as prescribed in the Korean Industrial Standards ranging from D13 to D51. With these experimental variables, specimens including conventional steel rebar are tested. Table 3 shows the variable name for each specimen, and the interlocking length by the length of specimen according to the steel rebar diameter is calculated according to the Korean Industrial Standards. The specimen's list is shown in Table 2.

Table 2. Specimen's List (Up-Set Coupler/Screw Coupler/Conventional steel rebar)

Bar No.	Variable name	Yield class	Steel rebar diameter (mm)	Test method	Specimen's length (mm)	Interlocking length (mm)
D13	U-D13-S-1 S-D13-S-1 C-D13-S-1	SD400	12.7	Static tensile test	347	127
D16	U-D16-S-2 S-D16-S-2 C-D16-S-2		15.0		379	159
D19	U-D19-S-3 S-D19-S-3 C-D19-S-3		19.1		411	191
D22	U-D22-S-4 S-D22-S-4 C-D22-S-4		22.2		442	222
D25	U-D25-S-5 S-D25-S-5 C-D25-S-5		25.4		474	254
D29	U-D29-S-6 S-D29-S-6 C-D29-S-6		28.6		506	286
D32	U-D32-S-7 S-D32-S-7 C-D32-S-7		31.8		538	318
D35	U-D35-S-8 S-D35-S-8 C-D35-S-8		34.9		569	349
D38	U-D38-S-9 S-D38-S-9 C-D38-S-9		38.1		601	381
D41	U-D41-S-10 S-D41-S-10 C-D41-S-10		41.3		633	413
D51	U-D51-S-11 S-D51-S-11 C-D51-S-11		50.8		728	508

Table 3. Establishment of specimen name

(S/U/C)-D13-S		
(S/U/C)	Variable name	U : Up-set Coupler S : Screw Coupler C : Conventional Steel rebar
D13	Steel rebar diameter	
S	Static tensile test	

3.3 Test Method

For steel rebar, chiefly the Shimadzu tension 2,000 kN universal test machine (UTM) is used. The static tensile test is conducted with a speed of 0.2 ㎜/sec until the steel rebar is ruptured. Loading test with an appropriate speed is conducted until a half of the load equivalent to the tensile strength prescribed in materials specifications under the International Standards according to the ISO 6892 [Test pieces for tensile test for metallic materials]. Beyond the half load, the standard requires a speed of 20% - 80%/min; thus the test herein is conducted at the speed of 0.5N/sec.

Also, the tensile strength of specimens that include joint according to ISO 6935 should be above the actual tensile strength of conventional steel rebar of the same kind. For the specimen assessment criteria, the tensile strength of each specimen should be over 125% of the minimum yield strength of the base steel rebar according to ACI 349. Thus, based on these values, the possibility of using the up-set coupler is examined.

(a) Conventional steel rebar (b) Up-Set Coupler (c) Screw Coupler

Fig 7. Outline of tensile test

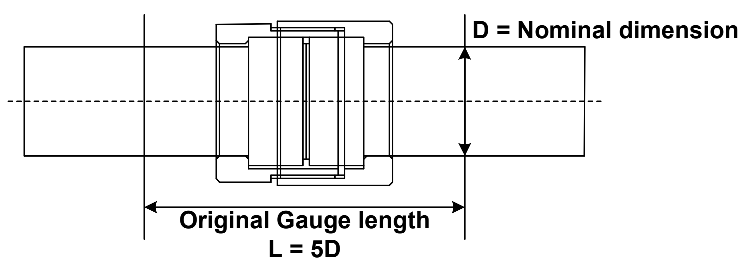


Fig 8. Original gauge length

3.4 Analysis and Review of Tension Properties Test Results

Table 4. Shows the test results for conventional steel rebar. Each steel rebar showed yield strength of over 400Mpa, and the location of rupture was all within the Original gauge length. The Original gauge length for tensile test was determined as 5D according to ISO 6935 (Fig 8.).

Table 4. Tensile test results for conventional steel rebar

Bar No.	Specimen name	Yield strength (MPa)	Remarks
D13	C-D13-S-1	424.1	SD 400
D16	C-D16-S-1	412.2	
D19	C-D19-S-1	463.5	
D22	C-D22-S-1	420.9	
D25	C-D25-S-1	443.7	
D29	C-D29-S-1	499.3	
D32	C-D32-S-1	465.1	
D35	C-D35-S-1	407.6	
D38	C-D38-S-1	434.9	
D41	C-D41-S-1	410.2	
D51	C-D51-S-1	412.0	

Table 5. Tensile tests results for screw couplers

Bar No.	Specimen name	Tensile strength (MPa)	$\frac{Tensile\ \ strength\ \ of\ \ Screw\ \ Coupler}{Yield\ \ strength\ \ of\ \ Conventional\ \ steel\ \ rebar} \times 100$
D13	S-D13-S-1	578.9	- Each tensile strength exceeds 125% of the nominal yield strength (500MPa).
D16	S-D16-S-2	586.3	
D19	S-D19-S-3	606.8	
D22	S-D22-S-4	603.2	
D25	S-D25-S-5	572.8	
D29	S-D29-S-6	602.9	
D32	S-D32-S-7	588.9	
D35	S-D35-S-8	571.6	
D38	S-D38-S-9	578.5	
D41	S-D41-S-10	606.3	
D51	S-D51-S-11	595.9	

Table 6. Tensile tests results for up-set couplers

Bar No.	Specimen name	Tensile strength (MPa)	$\frac{Tensile\ strength\ of\ Up-Set\ Coupler}{Yield\ strength\ of\ Conventional\ steel\ rebar}\times 100$
D13	U-D13-S-1	609.9	
D16	U-D16-S-2	562.9	
D19	U-D19-S-3	563.4	
D22	U-D22-S-4	644.4	
D25	U-D25-S-5	607.7	
D29	U-D29-S-6	630.1	- Each tensile strength exceeds 125% of the nominal yield strength (500MPa)
D32	U-D32-S-7	617.8	
D35	U-D35-S-8	600.7	
D38	U-D38-S-9	635.1	
D41	U-D41-S-10	613.8	
D51	U-D51-S-11	662.6	

Table 5. Shows test results for screw couplers. In all specimens conforming to the Korean Industrial Standards, a sudden rupture was created in the base steel rebar within the Original gauge length. Each specimen showed a high performance level which is 90MPa greater than 500Mpa (125% of the prescribed yield strength of 400Mpa). And, the tensile strength of the base steel rebar was found to be 30MPa greater than 560MPa.
Table 6. Shows static tensile test results for up-set coupler conventional steel rebar by diameter. With up-set coupler joining, most of rupture points were created within the Original gauge length, taking on typical steel rebars tensile rupture shape. The yield strength of each specimen showed a high level, which was 112MPa greater than 500MPa (125% of the prescribed yield strength of 400MPa). And, the tensile strength of each specimen was found to be 52 MPa higher than the base steel rebar's tensile strength of 560MPa.

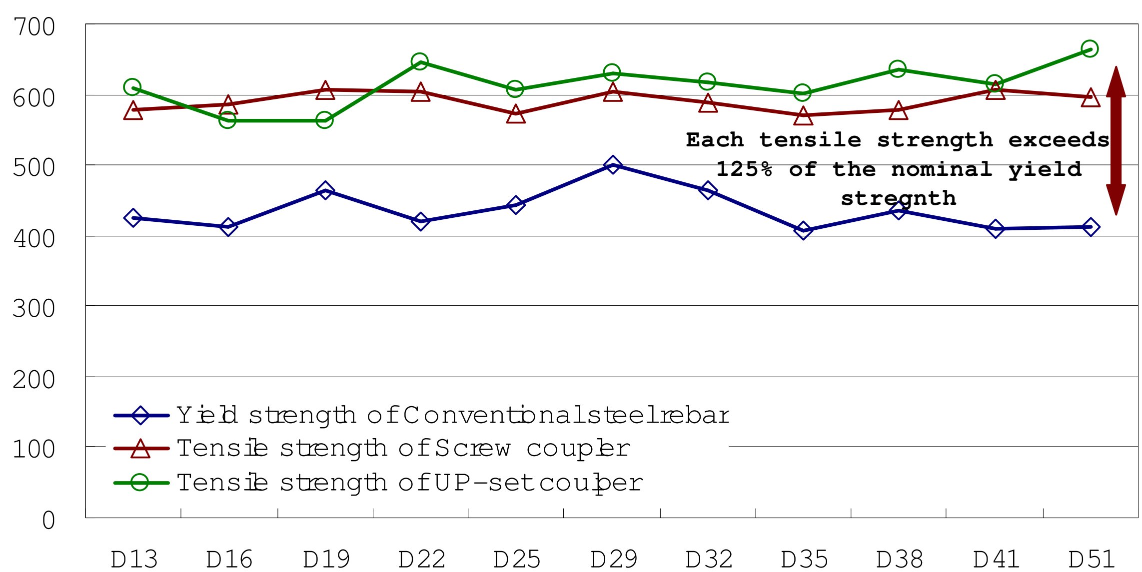


Fig. 9. Strength comparison by specimen

Table 7. Tensile strength by specimen

Category	Specimen name	Tensile strength(Mpa)	Rupture type
Conventional Steel rebar	C-D25	584.3	Tension failure
	C-D29	566.0	Tension failure
	C-D32	585.0	Tension failure
Screw Couplers	SC-D25	561.4	Base steel rebar rupture
	SC-D29	604.2	Base steel rebar rupture
	SC-D32	594.4	Base steel rebar rupture
Up-Set Couplers	US-D25	607.7	Base steel rebar rupture
	US-D29	630.2	Base steel rebar rupture
	US-D32	617.8	Base steel rebar rupture

Table 7. and Fig 10. Show a comparative analysis of steel rebar with a diameter of D25, D29, and D32 which are currently the most widely used. In most of specimens, the tensile strength was found to be similar, and overall, all the tensile strength figures were found to meet the ISO. Thus, as part of the efforts to address the lowered workability due to clustering associated with steel rebar lap joining further research such as fatigue test and structural test in addition to tensile test will determine the possibility of using the up-set coupler.

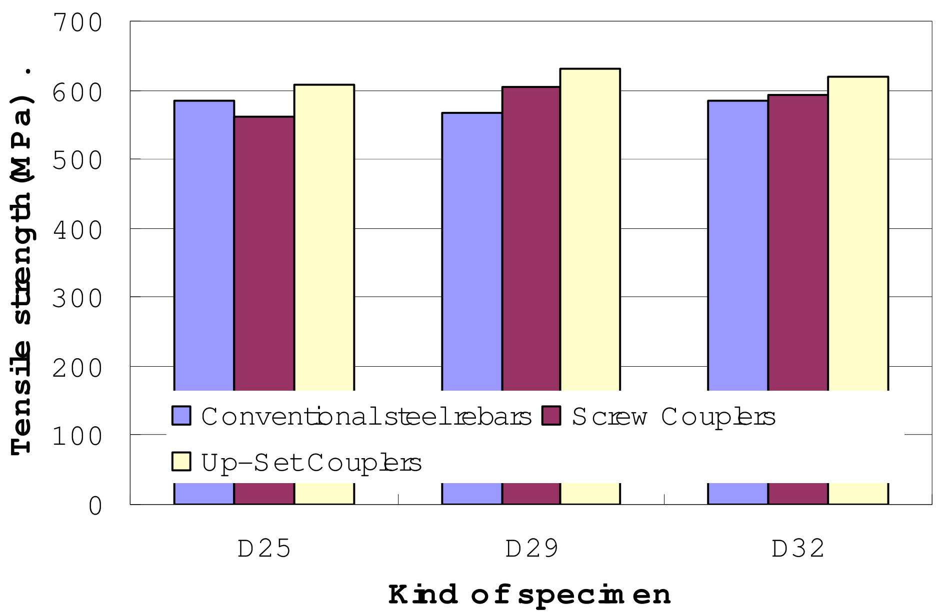


Fig. 10. Tensile strength by the kind of specimen

4. CONCLUSION

This paper examined the performance of mechanical joints of steel rebar with great diameter for use in high-rise and large buildings. It examined the performance of specimens with new-concept mechanical joints in an attempt to improve shortcomings of the existing steel rebar joining methods. It also evaluated the performance of mechanically joined steel rebar devised for speedy construction. The test results are outlined as follows.

1) The specimens of the current screw coupler joined steel rebar were tested; all of them met the ISO. The resulting yield strength was found to be 90 MPa greater than 500 MPa (125% of the prescribed yield strength of 400 MPa), and the resulting tensile strength was found to be 30 MPa greater than the base steel rebar's tensile strength of 560 MPa.
2) Up-set coupler joined steel rebar were tested, and they were ruptured in the base steel rebar. As with screw couplers, the yield strength was found to be 112 MPa greater than 500 MPa (125% of the prescribed yield strength of 400 MPa meeting the ISO). Screw couplers were all found to have a similar tensile strength.

REFERENCES

1. ISO 6892 Metallic materials – Tensile testing at ambient temperature.
2. ISO 6935 – 1 Steel for the reinforcement of concrete – Part 1 : Plain bar
3. ISO 6935 – 2 Steel for the reinforcement of concrete – Part 2 : Ribbed bar
4. Park, Sun-Kyu. and Lee, Kwal. and Ko, Won-Jun. "*An Experimental Research on the Flexural Behavior of Concrete Beams with Lock Joint Coupler Bars*", Korea Structure Maintenance Institute Journal. Vol. 4, No. 3, July 2000, pp.197-204.
5. Rezansoff, T. and Akanni, A. and Sparling., B.(1993), "*Tensile Lap Splices under Static Loading; A review of the Proposed ACI 318 Code Provisions,*" ACI Structural Journal. July-August, pp, 374-3384
6. Wang, C. K. and Salmon, C. G. (1985), Reinforced Concrete Design, Fourth Edition, Hoper & Row Publishers, New York, N.Y.
7. Mehta, P. K. (1995), Concrete, Prentice Hall.