

Development of Shell-Inserted-Joint (SIJ) for Improving Steel Installation Efficiency

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Abstract: Mechanical splices are commonly used to connect reinforcing bars in modern concrete structures. Recently, due to the tendency to increase the size of reinforced concrete structures, the importance of reinforcing bars has been increased. Commonly, lap splices, welded joints and mechanical splices are used in the field, yet lap splices are the most frequently used due to their workability and low price. However, such drawbacks of lap splices have caused material overuse and degradation of concrete quality. Mechanical splices on the other hand, overcame the existing issues of traditional methods, but often have complex design of the shapes and require advance steel molding techniques, SIJ simplified the design and production process by excluding separate sleeves for injecting mortar and by selecting fabrication process based on seamless pipe. also let workers visually check the status of the joints. This newly developed joint reduced multiple installation processes into one step which takes only few seconds to install with just single worker. Furthermore, by inserting an inspection hole in the product, it allowed workers to visually check the connection status of the joints and at the same time it allowed mortars to be entered the hole which enhanced the bond strength. In this paper, an extensive experiment was carried out to investigate the effectiveness of the joint at the same time to secure the national design standard.

Date of Submission: 07-06-2019

Date of acceptance: 22-06-2019

I. Introduction

In modern construction, due to the tendency of increase in the size of reinforced concrete structures, the importance of reinforcing bars has been expanded gradually. Steel rebars usually supplied in stand lengths due to fabrication, transportation capacity, as a result, splicing rebars are inevitable. Traditionally, lap splice was widely used in construction field until few setbacks have aroused.[1] Even though lap splice is famous for its workability and low-price, lap splice typically requires 50 to 70 times the diameter of the bars to be functional and it can require lengths greater than 30 bar diameters(db) which causes overuse of material. Also, it can be time consuming and often cause bar congestion within the concrete especially when large rebar sizes are used. [2-4]

Accordingly, Shell-Inserted-Joint (SIJ) was developed to improve the drawbacks of the existing mechanical splices. Where current products have complex design of the shapes and require advance steel molding techniques, SIJ simplified the design and production process by excluding separate sleeves for injecting mortar and by selecting fabrication process based on seamless pipe. also let workers visually check the status of the joints. [5]

In this paper, a novel working mechanism was provided for interlocking rebar and the splice. Moreover, extensive experiment was carried out to investigate the effectiveness of the joint at the same time to secure the national design standard.

II. Design and Test Results



Fig no 1. Shell Inserted Joint (SIJ)

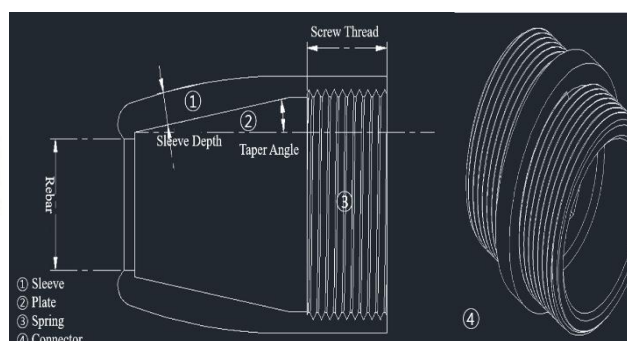


Fig no 2. Sleeve, Plate, Spring, Connector

As shown in Fig no 2 and 3, the SIJ is composed of four parts—sleeve, plates, spring and connector. Each end of the two sleeves, there is a hole for the rebar, and the sleeves are connected by the connector. A hole on the sleeve is for inspecting the connection state between the rebar and SIJ at the same time allows mortars to be inserted to increase the bonding strength. (Fig no 1) When a worker inserts a rebar, it pushes the plates back so that their sawtooth catches and connects with the spring as the rebar reaches the end of the sleeve.

Material Selection

The priority consideration in choosing sleeve material is strength. In addition, productivity, cost and heat treatment effect were considered. SM45C is commonly used material for currently available mechanical splices due to availability in the market and low cost. However, for Shell Inserted Joint, SCM440, 4140 for American Iron and Steel Institute (AISI) was selected for the material because of its uniform carbon component which has an advantage in quality control of heat treatment. Chemical compositions and mechanical property of SCM440 is shown in Table no 1.

Shell Inserted Joint Design

Primary function of the sleeves is to absorb tensile stress generated by the reinforced bars. However, in order to be function properly, the connection state of splices is crucial. Therefore, a visual inspection hole was designed which enables a worker to check the fastening state of the two reinforcing bars. (Fig no 3.)

The taper angle was smoothly pushed in at the inflow of the reinforcing bar at 10 degrees and designed to have high pressing force when the tensile force was applied. The grooves of the initial side were designed to increase the frictional force between the concrete and the reinforced concrete joint and to be convenient for assembly during the concrete pouring but were excluded from the design due to the difficulty of manufacture and the difficulty of the manufacturing process. The heat treatment process of the sleeve was done by Quenching and Tempering (Q/T) in order to obtain high strength and toughness in various steel grades and the hardness value is HRC 40 ~ 42 so that strength and toughness are appropriately matched.

In plates design process, the angle between the sawteeth, Θ decided to be 60 degrees. Since the number of sawteeth along with their length are directly related to the contact surface of a rebar, they were designed to contact two ribs in all sizes of reinforcing bar. The pitch from 13 to 16mm designed in 1.5 pitch, 22 to 25mm in 2.0pitch, 29 to 35mm in 2.5pitch. The connector of SIJ has the main function of fixing the elastic spring and the two sleeves together. Same as the sleeves and the plates, the material of the connector was used with SCM440 which is superior in mechanical properties and heat treatment performance.

Table no 1: Shows chemical compositions and machinal properties of SCM440.

C	Si	Mn	P	S	Cr	Mo	Ni	Fe
0.39	0.26	0.91	0.00	0.01	1.02	0.15	-	Bal.
Vickers Hardness [Hv]		Yield Strength [Mpa]		Tensile Strength [Mpa]		Elongation Rate [%]		
340		1010		1094		17.8%		



Fig no 3. 3D model of SIJ

Tensile Test of SIJ

A tension test was planned with 8 different reinforced bar sizes (D13, D16, D19, D22, D25, D29, D32, D35). The test variables are steel grade of rebar, and the size of the splice. SD400, SD500 and SD600 were used in the test while the splice was produced by using SM440 material. Based on KS D0249, the test targeted to meet minimum of 125% of its design yield strength.[6] Minimum standard of each steel grades has shown in Fig no 6.

Korea Construction Standard (21 design standard, 21 standard specification) has been modified to, "Construction Standard Code System" (Korea Design Standard (KDS) Korea Construction Standard (KCS)) since January 2018. Therefore, after the modification (done by Ministry of Land, Infrastructure and Transport Notice No. 2016-438, July 6, 2016), the performance evaluation of the product was followed by "Construction Standard Code".



Fig no 4. Tensile testing machine (INSTRON)



Fig no 5. SIJ for D13, D16, D19, D22, D25, D29, D32, D35

As shown in Fig no 5, the test was conducted with uni-directional tensile testing machine (INSTRON) which applies the maximum of 2000kN load in the direction of load of the specimen. The test was designed to measure the displacement and the tensile stress of the testing rebar. The steel rebar was cut to a length of approximately 80cm and applied the load until it reaches rupture strain. The tensile tests were repeated with 8 different bar sizes along with three different steel grades—SD400, SD500 and SD600. D13 only manufactures in SD400 and SD500, therefore only two steel grades were examined. Based on the tensile strength test, rebars with SIJ have met Korea Construction Standard.



Fig no 6. Tensile test results

According to ACI-318 [6] and Korean Building Code [7], the mechanical splice for rebar require 1.25 times greater tensile strength of specified yield strength f_y of rebar. As Fig no 10. shows each tech subjects have reached the standard from Korea Construction Standard (KS D 0249). From the tests results, it can be expected to replace traditional lap splice while maintaining the requirements from the codes.

Hardness Test

The developed product is a member that connects reinforcing bars at on-site and durability and abrasion resistance are required. Therefore, the material of each part and its hardness must be studied thoroughly. Especially, since the developed product is an industrial material, productivity and economic feasibility are also taken into consideration.

Table no 2: Shows the hardness test results of the parts

Parts	Heat Treatment	Required HRC	Results (HRC)
Sleeve	Q.T	42~45	45
Connector	Q.T	42~45	46
Plates	Carburizing	58~60	60

Working Mechanism

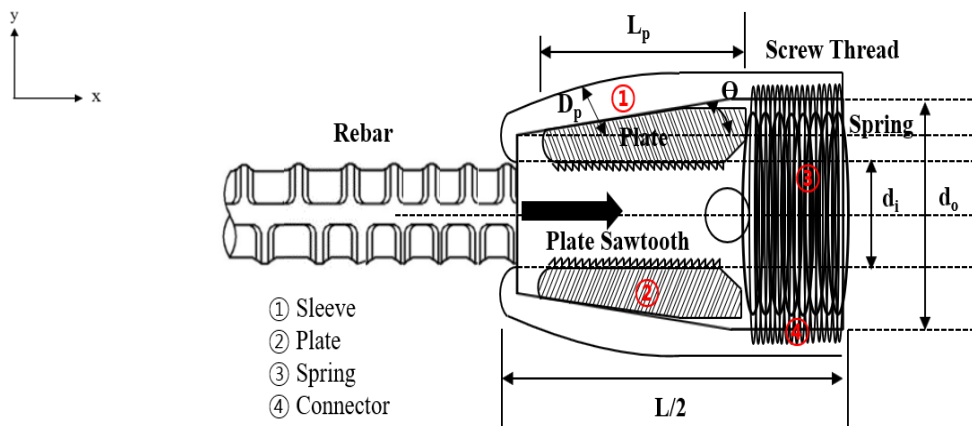


Fig no 7. Detail of Shell-Inserted-Joint

Shell Inserted Joint has a geometric feature in which the plates are fixed in positions by mutual close contact between the lateral edge faces in the sleeves. Therefore, it is not necessary to form grooves or ribs for supporting the fixed body on the inner surface of the sleeve and there is no need to provide additional structure

for supporting the fixed body which ultimately greatly simplified the design structure of the splice. The working mechanism of the SIJ is as follows.

As Fig no 7 shows, there are four main parts in SIJ—sleeve, plate, spring and connector. Normally, one sleeve is consisting of three identical shapes of plates as Fig no. 8 and 9. These plates have the same slope as the central axis x of the splice and by combining them, cylinder shape is formed which designed to fit inside of the sleeve.

When the rebar gets inserted into the SIJ, the plate simultaneously pushes back towards the spring while the sawteeth on the plate catch the rebar. In order to have ideal bonding strength, the length of the plate L_p and the depth of the plate D_p are important which are decided according to the diameter of the rebar. When the insertion is completed, the elastic spring that has undergone compressive stress and pushes the plates with counter force to repel the plate so that plates are able to hold the rebar.

The entire outer surface of the plates is always supported on the surface of the inner side surface of the sleeve before or after the rebar insertion, so that the tilting movement of the fixed plate does not occur. Also, the tensile strength of the splice is improved since the stress transfer in the surface is maximized whereas the external tensile force is effectively dispersed.

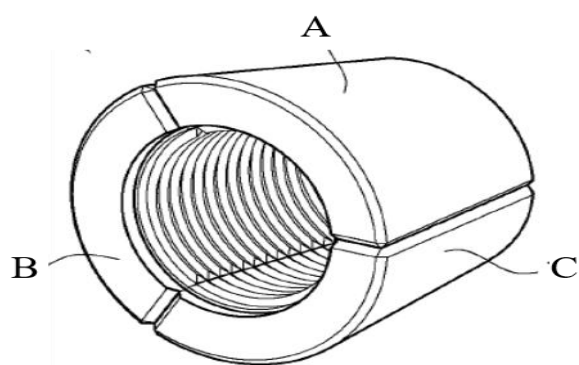


Fig no. 8 SIJ plates in cylinder shape

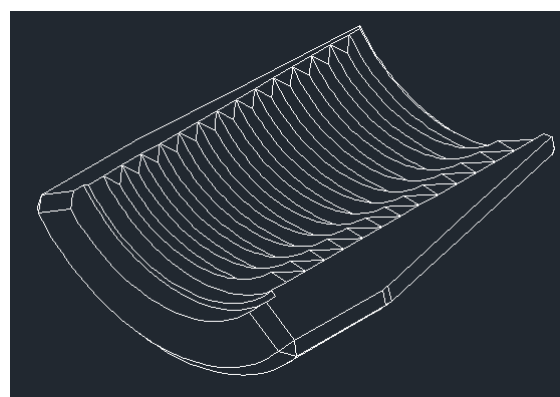


Fig no. 9 CAD model for plate with sawteeth

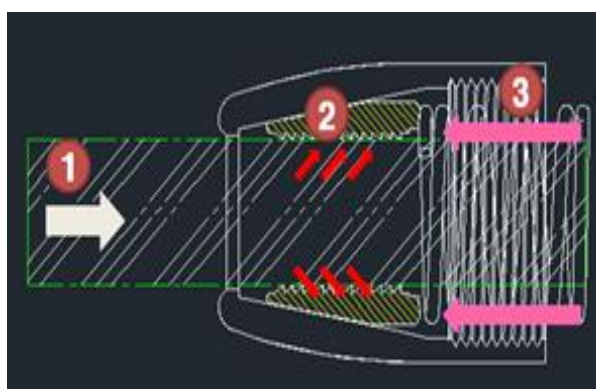


Fig no. 10 Working mechanism of SIJ

Cost Analysis


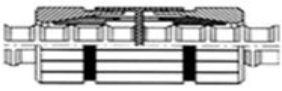


In order to study economic aspect of the product, cost comparison was conducted based on labor cost by working time. On-site mechanical joints were chosen as test samples and the first half of 2018 Korea wage cost[8] was applied in the analysis. The assumptions for the comparison of labor costs over time are as follows.

Labor cost: 1 pair of 2 workers – steelworker (189,303won), normal worker (109,819 won)

1 pair of 1 worker – steelworker (189,303won)

Working time: 8 hours per day

Table no 3: Shows cost analysis of on-site mechanical joints

	Splice Types	Install Duration / (Required No. of workers)	Maximum Daily Workload (section/hour)	Daily labor cost (won)	Required working days (5000sections)	Total Labor Cost (won)
	Solid Type	5min (2)	96 (12)	299,122	521	155,842,562
	Detachable Type	7min (2)	68(8.6)	299,122	736	220,153,792
	Wedge Shell Joint	3min (2)	160(20)	299,122	313	93,625,186
	Shell Inserted Joint	10sec (1)	2880(360)	189,303	18	3,407,454

According to Table no 3, when SIJ was selected on a project, approximately 90,000,000 won to 150,000,000 won of labor costs can be reduced.

III. Conclusion

In this paper, it investigated the reliability and effectiveness of newly developed mechanical splice, Shell Inserted Joint (SIJ). Working mechanism of SIJ was developed at the same time the tensile test and the hardness tests were conducted based on Korean Building Code. From the test results, the following conclusions were obtained.

- 1) Throughout the study, 8 different sizes of splices were tested with two steel types—SD500 and SD600. All subjects were capable of 125% of specified yield strength f_y of rebar.
- 2) Working mechanism of SIJ were developed which the reinforcement is inserted by the action of the elastic body inside the reinforcing bar. Even a single worker will be able to easily install the reinforcing bars where the conventional way the use of a tool or skilled workers were needed.
- 3) The inspection hole was designed in the product so that a worker can inspect the fastening state of the reinforcing bars by visually check hole on the side of the sleeve. Also, when concrete is poured, the concrete penetrates through the inspection hole, in result, it improves the bonding strength between the rebar and the SIJ.
- 4) A cost analysis has been conducted in order to investigate the economic benefits of SIJ. In results, approximately 90,000,000 won to 150,000,000 won of labor costs can be reduced compared to existing mechanical splices.

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