ICCEPM 2024 https://dx.doi.org/10.6106/ICCEPM.2024.0010
The 10th International Conference on Construction Engineering and Project Management
Jul. 29-Aug.1, 2024, Sapporo

A Basic Study on Comparative Analysis of the Characteristics and Performance of Different Types of Mechanical Rebar Coupler for Sustainable Built Environment

Jeeyoung LIM [1], Ayomi Dita Rarasati[2], Sunkuk KIM [3*]

[1] *Department of Architectural Engineering, Kyung-Hee University, Republic of Korea,* E-mail address: jyounglim@khu.ac.kr
[2] *Civil Engineering Department, Universitas Indonesia, Indonesia,* E-mail address: ayomi@eng.ui.ac.id
[3*] *Department of R&D, Earth Turbine Co., Ltd., Republic of Korea,* E-mail address: kimskuk@khu.ac.kr

Abstract: Rebar lap splice is the most commonly used at construction sites because it does not require any additional equipment or labor's skills. Rebar lap splice has high construction costs because they require approximately 15% more rebar due to the overlap length. To solve these problems of rebar lap splice, mechanical rebar coupler was developed. Mechanical rebar coupler has a strong bonding force, helping to keep the structure safe even during earthquakes. In addition, mechanical rebar coupler is suitable for modular construction and easy to construct, so the construction period can be shortened. And mechanical rebar coupler can reduce the amount of rebar compared to other joint methods, thereby reducing CO2 emissions. Despite these advantages, the use of mechanical rebar couplers is not widespread except in some developed countries. This is because the types and characteristics of mechanical rebar couplers vary widely, making it difficult for construction engineers to choose. Existing research has only been conducted on mechanical rebar couplers in terms of structural experiments. And there is no research that classifies and analyzes the shapes of rebars. Hence, it should be analyzed the characteristics of mechanical rebar couplers in terms of construction methods for each shape. Therefore, the objective of this study is a basic study on comparative analysis of the characteristics and performance of different types of mechanical rebar coupler for sustainable built environment. The most efficient mechanical rebar coupler was derived for each construction site environment.

Key words: mechanical rebar coupler, comparative analysis, sustainable built environment, coupler characteristics, modular construction

1. INTRODUCTION

In reinforced concrete (RC) structures, splices are required due to limited length of rebar [1], and transportation issues [2-3]. In other words, splices connect reinforcing bars in RC structures such as walls, columns, beams, slabs, and joints. The rebar lap splice is the most commonly used at construction sites around the world because it does not require any additional equipment or operator skills. A rebar lap splice requires approximately 15% more rebar due to the overlap length, increasing construction costs[4]. To solve this problem of rebar lap splice, mechanical rebar coupler (MRC) was developed. MRC has a strong bonding force, helping to keep the structure safe even in the event of an earthquake. In addition, because MRC is easy to construct, the construction period can be shortened, and the amount of rebar can be reduced compared to other joint methods, thereby reducing CO2 emissions.

Despite the above advantages, the use of MRC is not widespread except in some developed countries. This is because the types and characteristics of MRC vary widely around the world, making it difficult for construction engineers to choose. Existing research has only been conducted on MRC in terms of structural experiments, and there has not been any research yet that has classified and analyzed reinforcement by shape, such as deformed rebar, threaded rebar, and end-processed rebar. Therefore, it is needed to analyze the characteristics of MRC in terms of construction methods for each rebar shape. Therefore, the objective of this study is a basic study on comparative analysis of the characteristics and performance of different types of MRC for sustainable built environment.

2. PREVIOUS STUDY

In the research on MRC, Guo et al. (2020) studied six test groups about insufficient grout height, insufficient compaction, rebar offset, insufficient rebar anchor length, timed grouting, and control group to identify rebar connection defects for half grouting sleeves [6]. Tazarv and Saiidi (2016) classified tension-compression mechanical rebar joints into five general types depending on the fixation mechanism [7]. Dahal and Tazarv (2020) classified into six types of MRCs, including threaded couplers, headed bar couplers, swaged couplers, grouted sleeve couplers, shear screw type, and hybrid. These studies were classified according to the structural mechanism of MRC [1].

Han et al. (2018) proposed epoxy mortar-filled threaded couplers and conducted experiments for the seismic behavior of precast columns [8]. Dabiri et al. (2022) developed and verified a machine learning-based model for estimating the ultimate strain of MRC [9]. In addition, many structural experimental studies of MRC were conducted [10]. And Dabiri et al. (2022) conducted a research review on splice methods used for reinforcement steel bars, but an overall rebar splicing method and experimental approach were conducted [2]. In other words, research on MRC has been conducted in terms of structural experiments, and there has not been any research yet that has classified and analyzed the rebar shapes such as deformed rebar, threaded rebar, and end-processed rebar.

3. CLASSIFICATION of MRCS

In this study, considering the construction characteristics at construction sites, MRC is classified into three types, including deformed rebar, threaded rebar, and end-processed rebar, depending on the shape of the rebar as shown in Figure 1.

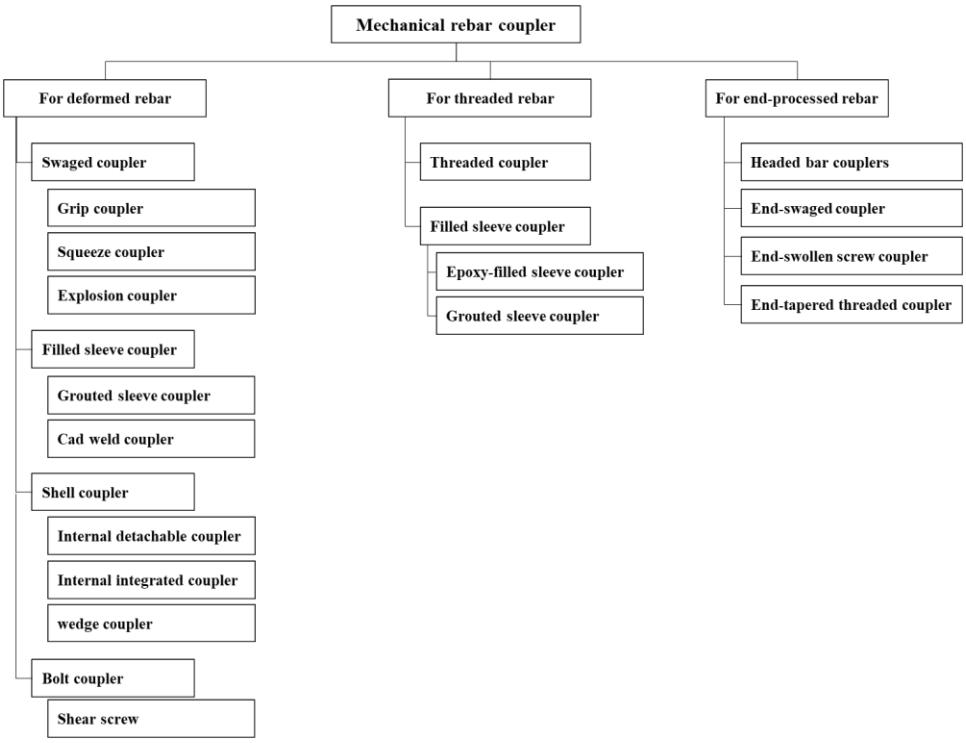
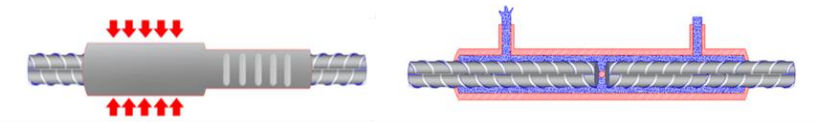


Figure 1. Classification of MRC

2.1 For deformed rebar

2.1.1 Swaged couplers

As shown in Figure 2(a), swaged couplers are joined by inserting a sleeve between two rebars and then pressing them with a hydraulic press machine [2]. The lateral force applied to the sleeve by hydraulic pressure deforms the sleeve and fills the gap between the rebar ribs.



(a) Swaged coupler (b) Filled sleeve coupler

Figure 2. Swaged coupler and filled sleeve coupler

(1) Grip coupler

Grip coupler is a joint technology in which a cylindrical steel pipe is inserted into the end of a rebar and then intermittently pressed using a special hydraulic press machine, and the cylindrical steel pipe is inserted and joined to the joints of the deformed rebar. This coupler is a method of inserting reinforcing bars between sleeves using a G-Loc Sleeve, G-Loc Wedge, and Insert, pressurizing and tightening the sleeves. It can only be used for vertical reinforcing bars, and has the disadvantage of requiring considerable connection time.

(2) Squeeze coupler

Squeeze coupler uses a special hydraulic press machine to continuously compress in one direction along the axis of the sleeve, significantly shortening the connection time compared to the intermittent compression method. It is one of the MRC that is currently widely used.

(3) Explosion coupler

Explosion coupler is MRC that compresses a cylindrical steel pipe into the joints of deformed reinforcing bars by the explosive force of gunpowder. Explosion coupler has not been widely used recently.

2.1.2 Filled sleeve coupler

As shown in Figure 2(b), filled sleeve couplers are a method of joining by inserting a sleeve between two rebars to be joined and then filling the sleeve with filling material.

(1) Grouted sleeve coupler

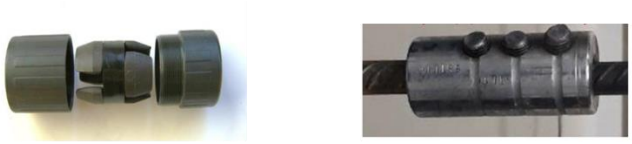
Grouted sleeve coupler is a method that fills mortar between a steel pipe and a deformed rebar and transfers the stress generated at the joints of the deformed rebar to the steel pipe through the mortar. Grouted sleeve couplers consist of three main parts: sleeve, grout, and two holes (grout inlet and grout outlet) [2]. After the bar is evenly inserted into the sleeve, the sleeve is filled with non-shrink high-strength mortar. Pour mortar through the inlet and use the outlet to remove air bubbles.

(2) Cad weld coupler

Cad weld coupler is a method of filling molten metal instead of mortar. This method has very good rigidity, but is not currently used often because it requires large equipment to heat the filler at the joint.

2.1.3 Shell coupler

As shown in Figure 3(a), Shell coupler is a method of joining reinforcing bars using a single body having a cylindrical joint shape, and is easy to construct on site. However, compatibility depending on the shape of the reinforcing bars is poor and rebar slip occurs, so follow-up work such as mortar filling is necessary.



(a) Shell coupler (b) Shear screw

Figure 3. Shell coupler and shear screw

(1) Internal detachable coupler

Internal detachable coupler is a method of separately fastening knits with grooves corresponding to the reinforcing bar nodes to the ends of the reinforcing bars to be connected to each other, and connecting them using an integrated coupler. The internally separated flat body does not require special equipment and has excellent construction properties for spiral and circular band reinforcement. Compatibility is good depending on the rebar manufacturer. It can also be a practical solution for rebars that cannot rotate in threaded couplers or join with shear screws or grout couplers. However, it takes a long time and costs to produce an internally separated type slab for deformed reinforcing bars. Initial slip can occur during tensioning, and it is difficult to visually detect the tightening strength.

(2) Internal integrated coupler

Internal integrated coupler is a method of connecting two reinforcing bars by joining them together to form one long knitted body with grooves corresponding to the reinforcing bar joints machined. It can be worked at the same time as rebar placement, and no special equipment is needed, so construction can be done simply on site. However, depending on the rebar manufacturer, compatibility is not possible, and there is a risk of deterioration in the constructability of spiral and circular band rebar. Applicability varies greatly depending on the shape of the rebar joint, and the coupler length is long and the outer diameter is large.

(3) Wedge coupler

Wedge coupler is a method of joining reinforcing bars using semi-cylindrical bars with a cylindrical joint shape and can be easily constructed on site. It has excellent compatibility to accommodate the diversity of reinforcing bar joint shapes, and enables strong connection and easy connection status inspection by wedges. There is no expansion or contraction when joining, and it is advantageous for joining columns and beams. It is a joint method that allows inspection of the construction condition, and the coupler strength is stronger than the strength of the reinforcing bar. Stable quality can be secured. However, if the reinforcing bars have different specifications, application is difficult. And the constructability of spiral and circular band reinforcing steel is reduced.

2.1.5 Bolt coupler - Shear screw

As shown in Figure 3(b), shear screw coupler (bar-lock or shear bolt coupler) is a method of connecting rebar using bolts installed in the sleeve [2]. Place a steel rebar of equal length in the sleeve and connect it by tightening the screw until the rebar is secure. This method is used for rebar that cannot be easily threaded. In other words, it can be applied to reinforcing bars that must be combined with reinforcing bars embedded in concrete or that cannot rotate, and can be used depending on the environment regardless of the shape. Tensile stresses are transmitted through friction between the screw tip and the bar surface and shear rails considered in the sleeve.

2.2 For threaded rebar

2.2.1 Threaded coupler

Threaded coupler is a general coupler used to connect threaded rebar [2]. Threaded coupler is easy to construct as there is no expansion or contraction during joining, and is advantageous for joining columns, and beams. When connecting threaded reinforcing bars, the problem of loosening between the coupler and the threaded reinforcing bars occurs, so this can be solved in the following way. The screw rebar joint is a method of joining the rebar by turning it into a joint coupler like a screw. This joint technology requires the presence of a spiral joint rebar. In addition, unlike general deformed reinforcing

bars, spiral joint reinforcing bars do not have transverse ribs, and the circumferential joints must be formed in a spiral direction like a screw. If the threaded rebar is not compatible, the connection must be made using a dedicated coupler corresponding to the threaded rebar produced by each production company.

2.2.2 Filled sleeve coupler

(1) Epoxy-filled sleeve coupler

Epoxy-filled sleeve coupler is an epoxy resin used to fix rebars and couplers, and hardens immediately upon injection. Unlike gas pressure welding, it does not require large tools, machines, or skilled workers. The injection tool uses a double cartridge epoxy gun.

(2) Grouted sleeve coupler

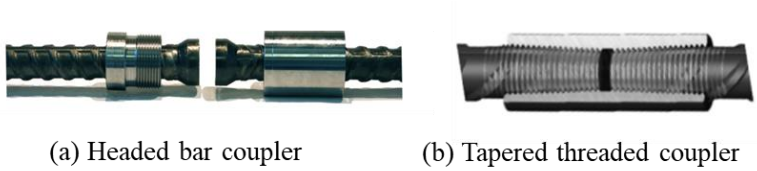
Grouted sleeve coupler is also suitable for the precast method. Grouted sleeve couplers can improve workability in both precast concrete members manufacturing and field construction work by reducing the diameter and shortening the coupler.

2.3 MRC for end-processed rebar

End-processed rebar are used for special purposes such as precast concrete members and line assembly methods by threading the ends of threaded reinforcing bars or deformed reinforcing bars, or friction-welding separate screws to the ends of reinforcing bars and joining them using couplers and nuts. It is a joint that is easy to use on the back.

2.3.1 Headed bar coupler

As shown in Figure 4(a), The mechanism of headed bar couplers is made by a small piece welded to the end of a rebar and a male/female component considered from the end of the rebar. Preparing rebar for headed bar couplers can be time consuming. Headed bar coupler can be a practical solution for rebars that cannot rotate in threaded couplers or join with shear screws or grout couplers.



(a) Headed bar coupler (b) Tapered threaded coupler

Figure 4. Headed bar coupler and Tapered threaded coupler

2.3.2 End-swaged coupler

End-swaged coupler is a method of swaging (pressing) the joints and ribs at the end of the rebar in cold (room temperature) processing the rolled screws and connecting them using a coupler with a female thread processed. End-swaged coupler is no expansion or contraction during joint fastening, and construction is easy, so fastening time is short. It is advantageous for joining columns and beams, and it is easy to ensure stable quality. The length and outer diameter of the coupler are small and do not significantly affect construction. However, factory production is required, and the higher the carbon steel, the more likely it is to reduce reliability due to work hardening caused by the mold. End-swaged coupler has a risk that the constructability of spiral and circular band rebar may be reduced, and reliability may be reduced when bending.

2.3.3 End-swollen screw coupler

End-swollen screw coupler is a method of expanding the cross section of the end of a rebar in the cold and then connecting it using a coupler with a female thread processed by cutting or rolling screws. There is no expansion or contraction when fastening joints, and special technicians are not required, making construction easy and fastening time short. However, there are concerns about changes in the steel structure due to hot working, and the toughness of the structure may decrease due to work hardening during cold working. Constructability of spiral and circular band rebar may be reduced, and

the length and outer diameter of the coupler are somewhat large, so they must be considered during construction. During screw processing, the length of the reinforcing bar decreases.

2.3.4 End-tapered threaded coupler

As shown in Figure 4(b), End-tapered threaded coupler is a method of connecting the ends of rebar by cutting threads into a tapered shape. The end of the rebar must be threaded and prepared considering the shape of the coupler. Through this method, reinforcing bars of different sizes can be connected. In this case, half of the sleeve is threaded for the first size of rebar and the other half is threaded for the other rebar. Properly forming the threads plays an important role in the performance of the coupler. In addition, this method does not expand or contract when joints are fastened, and have wide applicability in the field. However, this method coupler cannot be used in the construction of spiral and circular band reinforcing bars, and since the reinforcing bar base material is cut, there is a risk that the performance of the joint may be deteriorated. This method is constructed by rotating the rebar, so constructability may be reduced, and quality control based on fastening force is difficult.

4. MRCS COMPARISON

As shown in Table 1, the advantages of the mechanical rebar coupler were analyzed. Among the 16 types of MRCs, the explosion coupler has no advantages in terms of cost, construction time, quality, and safety, and has safety issues during construction.

Table 1. Comparison in terms of cost, time, quality, and safety

MRC classification for use	Detailed classification		Cost	Time	Quality	Safety
For deformed rebar	Swaged coupler	Grip coupler	X	X	X	○
		Squeeze coupler	X	○	X	○
		Explosion coupler	X	X	X	X
	Filled sleeve coupler	Grouted sleeve couplers	○	△	○	△
		Cad Weld coupler	X	○	◎	X
	Shell coupler	Internal detachable coupler	X	X	X	X
		Internal integrated coupler	X	○	△	○
		wedge coupler	X	X	○	○
	Bolt coupler	Shear screw	○	X	○	○
For threaded rebar	Threaded coupler		△	○	○	○
	Filled sleeve coupler	Epoxy-filled sleeve coupler	△	○	○	○
		Grouted sleeve coupler	△	△	○	○
For end-processed rebar	Headed bar couplers		X	X	X	X
	End-swaged coupler		X	X	X	X
	End-swollen screw coupler		X	X	X	X
	End-tapered threaded coupler		X	X	X	X

End-swollen screw coupler reduces the length of the reinforcing bar during screw processing, does not cause expansion or contraction when fastening the joint, and does not require special technicians, making construction easy and fastening time short. In addition, the tapered threaded coupler does not expand or contract when fastening the joint, and has wide applicability in the field. However, end-tapered threaded couplers cannot be used for spiral and circular band rebar construction, and since the reinforcing bar base material is cut, there is a risk of deterioration in joint performance. End-tapered threaded couplers are constructed by rotating the rebar, so constructability may be reduced, and quality control based on fastening force is difficult. Shear screw is connected by placing a steel rebar of the same length on the sleeve and then tightening the screw until the rebar is fixed. This method is used for rebar that cannot be easily threaded [2].

5. MRC PROPOSAL for SUSTAINABLE BUILT ENVIRONMENT

For sustainable built environment, it is proposed threaded coupler and epoxy-filled sleeve coupler. As shown in Figure 5(a), the coupler has an acceptable range for insertion length, so it provides sufficient performance even if insertion is somewhat insufficient. Figure 5(b) shows that the coupler has a design gap, so there is a gap between the screw joints, so even if the rebar is slightly twisted, immediate response is possible. As shown in Figure 5(c), all ribs of threaded joint rebar are in the form of threaded joints, so when a level difference occurs, the coupler can be connected immediately after cutting, enabling simple leveling.

(a) Rebar length tolerance (b) Design error cover (c) Simple leveling for rebar length

Figure 5. Advantages of the proposed MRCs

6. CONCLUSION

In this study, MRC was classified and analyzed by reinforcing bar shape, including deformed rebar, threaded rebar, and end-processed rebar. And it is proposed a threaded coupler and an epoxy-filled sleeve coupler for a sustainable built environment in this study. In the future, Research applied to case projects and the characteristics of special couplers are needed.

ACKNOWLEGEMENTS

This work was supported by the National Research Foundation of Korea (NRF) grants funded by the government of the Republic of Korea (MOE) [No. 2021R1C1C2094527]

This work was supported by the National Research Foundation of Korea (NRF) grants funded by the government of the Republic of Korea (MOE) [No. 2022R1A2C2005276].

REFERENCES

[1] P.K. Dahal, M. Tazarv, “Mechanical bar splices for incorporation in plastic hinge regions of RC members”, Construction and Building Materials. Vol. 258, pp. 120308, 2020.

[2] H. Dabiri, A. Kheyroddin, and A. Dall'Asta. "Splice methods used for reinforcement steel bars: A state-of-the-art review." Construction and Building Materials Vol. 320, pp. 126198, 2022.

[3] G. Metelli, J. Cairns, G. Plizzari, “The influence of percentage of bars lapped on performance of splices”, Materials and Structures, Vol. 48, no. 9, pp. 2983–2996, 2015.

[4] R.T.S. Mabrouk, A. Mounir, “Behavior of RC beams with tension lap splices confined with transverse reinforcement using different types of concrete under pure bending”, Alexandria engineering journal, Vol. 57, no. 3, pp. 1727–1740, 2018.

[5] A.M. Tarabia, Z.I. Mahmoud, M.S. Shoukry, A.A. Abudina, “Performance of RC slabs with lap splices using headed bars”, Alexandria engineering journal, Vol. 55, no. 3, 2729–2740, 2016.

[6] H. Guo, J. Zhang, and C. Wang. "Experimental study on influence of connection defects on joint strength of half-grouted sleeve splicing of rebar." Advances in Civil Engineering, Vol. 2020, pp. 1-15, 2020.

[7] M. Tazarv, M.S. Saiidi, “Seismic design of bridge columns incorporating mechanical bar splices in plastic hinge regions”, Engineering Structures, Vol. 124, pp. 507–520, 2016.

[8] W. Han, Z. Zhao, J. Qian, Y. Cui, S. Liu, “Seismic Behavior of Precast Columns with Large-Spacing and High-Strength Longitudinal Rebars Spliced by Epoxy Mortar-Filled Threaded Couplers”, Engineering Structures, Vol. 176, pp. 349–360, 2018.

[9] H. Dabiri, V. Farhangi, M.J. Moradi, M. Zadehmohamad, M. Karakouzian, “Applications of Decision Tree and Random Forest as Tree-Based Machine Learning Techniques for Analyzing the Ultimate Strain of Spliced and Non-Spliced Reinforcement Bars”, Applied Sciences, Vol. 12, no. 10, pp. 4851, 2022.

[10] A. Kheyroddin, H. Dabiri. “Cyclic performance of RC beam-column joints with mechanical or forging (GPW) splices; an experimental study”. Structures, Vol. 28, pp. 2562-2571, 2020.