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Experimental Study on the Performance of Mechanical Coupler Splice Made of Rebar Under Monotonic Loading

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Abstract
The lap splice method presents a drawback due to reinforcement congestion, affecting the pouring and evenness of the concrete. Additionally, lap splicing significantly contributes to construction waste. As a result, research was conducted on mechanical connections using reinforcements to reduce construction waste and demonstrate the feasibility of these splices. In this study, the threaded coupler with standard national coarse threads splice method was employed, and tests were conducted following ASTM A1034-10a standards with monotonic tensile loading. Test specimens were created using 13 and 16 mm reinforcement sizes, varying the length and diameter of the coupler, and including welding at the coupler ends. The test results demonstrated that reinforced bars with splices exhibit a stress-strain relationship similar to intact reinforcement. However, these reinforced bars with splices did not meet the requirements outlined in SNI 2052:2017 concerning maximum stress and strain, including their comparison. Therefore, the utilization of these splices is not suitable for critical load-bearing areas.

INTRODUCTION

Reinforcing bar splice is essential in reinforced concrete construction, as efficient and strong connections between reinforced concrete reinforcements are crucial for ensuring structural integrity and user safety. However, the requirement to adjust standard bar lengths to meet the specific needs of individual construction projects using trimming often leads to steel rebar becoming a significant contributor to construction waste. (Nadoushani et al., 2018).

There are several commonly used applications of reinforcement connections in the construction of reinforced concrete structures. Reinforcement connections can be made in three ways: lap splice, welded splice, and mechanical splice (Lancelot, 1985).

Lap splice is one of the commonly used types of reinforcing bar splice in reinforced concrete structures. This connection is used to connect two reinforcements to become a single unit supporting the reinforced concrete structure. Furthermore, lap splice is known for being easy to execute while still being able to transmit stress closely approaching that of the intact reinforcement in a reinforced concrete structural component. (El-Azab & Mohamed, 2014) The lap splice method has a drawback: the congestion of reinforcements can affect the pouring and levelling of the concrete. The tighter the congestion, the more difficult it is to level, which can decrease the quality of concrete and increase dead load due to the weight of the reinforcements (Dabiri et al., 2022).

A mechanical splice can be used to overcome the drawbacks of a lap splice. A mechanical reinforcement connection involves using mechanical elements such as bolts, nuts, or plates to join reinforced concrete reinforcements. Several mechanical splices are known, including shear screw couplers, headed reinforcement couplers, threaded couplers, tapered threads, grouted sleeve couplers, and hybrid couplers. Among all the types of mechanical connections available, the dimensions, length, and type of coupler significantly influence its performance (Dahal & Tazarv, 2020). The connection of the coupler effectively transmitted stress well between two connected reinforcement bars. The performance of a coupler connection is unique and varies depending on the type of coupler used. (Moka & Rajendran, 2022). Using a reinforcing bar splice has a disadvantage: the potential reduction of ductility in the connection, whether a lap splice or a mechanical splice. (Kheyroddin et al., 2020)

Research has been conducted on mechanical splice using threaded connections with Parallel Threaded Couplers (PTC) and Parallel Threaded Sleeve Couplers (PTSC) with two loading methods; they are monotonic and cyclic. The monotonic loading results found that the maximum strain occurring in the intact reinforcement and the reinforcement with joints are the same. However, in cyclic loading, there are differences in the strain that occurs between the intact reinforcement and the reinforcement with joints (Bompa & Elghazouli, 2018).

Pull tests on reinforced bars with couplers have also been conducted, with the quality of the reinforcement used being 500 MPa and the quality of the coupler joint being 600 MPa. Based on the results of the experimental testing, the maximum tensile strength of the connected reinforcement was found to be 404 kN. However, this result is still below the requirement set by ACI 318, it had a minimum standard of 125 percent of the yield strength of the reinforcement. The reinforcement failure in this test occurred at the threaded portion, as there was a reduction in cross-sectional area and a concentration of stress due to the threaded cut. The comparison results show that the load and elongation are close for the intact reinforcement, but it has a shorter strain hardening phase. (Fig. 1)(Shokrzadeh & Nateghi-Alahi, 2022).

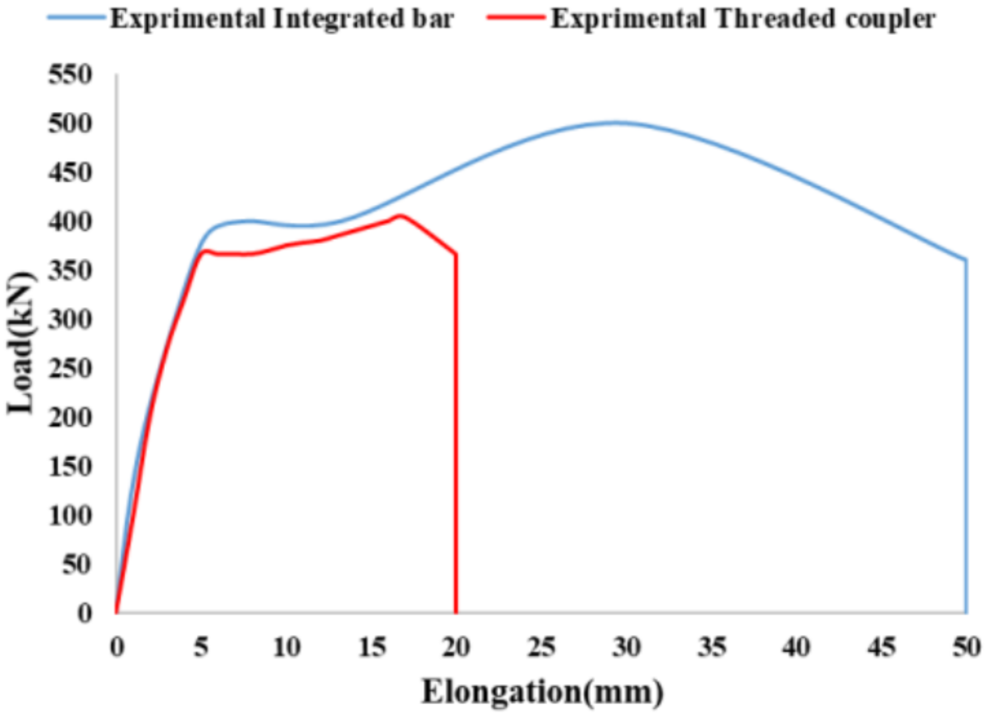


Figure 1. - Load- elongation curves obtained by experimental results (Shokrzadeh & Nateghi-Alahi, 2022)

Using coupler connections by enlarging the ends of the reinforcement before threading indicates an acceptable yield strength that can be sustained by both the complete and connected reinforcements, which tend to be relatively close. However, the connected reinforcement exhibits a higher maximum tensile strain at maximum stress than the unconnected reinforcement. (Kruavit et al., 2020)

Research about mechanical connections using grouted sleeves has been conducted. After testing, two types of failures were observed in both specimens. In the WBS specimen, the failure occurred in the form of detachment of the connected reinforcement from the grouting material or slip. In the THS specimen, the failure involved the rupture of the reinforcement outside the grouted connection location. (Ling et al., 2016)

For coupler connections in structures subjected to seismic loads, the failure should occur outside the coupler area, and the length of the coupler used should be less than 15 times the diameter of the connected reinforcement. The placement of coupler connections in the structure will significantly affect the structural performance, so it needs detailing on the structure. (Tazarv & Saiidi, 2016)

Based on previous research on mechanical reinforcement splices, all types of connections utilize materials designed explicitly for couplers. Therefore, in this study, a proposal for a mechanical splice using couplers made of reinforcement conducted. Using mechanical splice using reinforcement materials is expected to reduce construction waste by utilizing existing or leftover materials from previous projects.

This research aims to understand the behaviour of mechanical splice using reinforcement steel materials under monotonic tensile loading and determine whether the connections meet the specified criteria for mechanical reinforcement splices.

RESEARCH METHODS

In this study, the fabrication of a threaded coupler with standard national coarse threads was conducted (Figure 2). This method utilises a threaded connection between the reinforcement with external threads at its end and the coupler sleeve with internal threads. With this method, there is no need for enlargement of the reinforcement at the ends, which reduces the cross-sectional area of the reinforcement by 15-25% compared to the original area when threaded. Therefore, it is necessary to control the quality of the reinforcement. The size of the coupler sleeve is expected to have an equal or larger cross-sectional area than the reinforcement being connected.

Figure 2. Threaded coupler with standard national coarse threads (ACI Committee 439, 2007)

Based on ACI Committee 439 (2007), the cross-sectional area of the coupler sleeve used to connect the two reinforcement bars should be equal to the area of the joined reinforcement. Therefore, based on the calculation of the cross-sectional area of the reinforcement and the coupler sleeve, a diameter 19 mm coupler will be used to connect 13 mm diameter reinforcement bars, and according to the ACI Committee 439 (2007) the recommendation, a diameter 22 mm coupler should be used. For 16 mm diameter reinforcement bars, a 25 mm coupler will be used, following the recommendation of ACI Committee 439 (2007).

The length variable of the coupler connection is also considered by adding variations in coupler length for each connection. Based on previous studies conducted by Bompa and Elghazouli (2018) and Shokrzadeh and Nateghi-Alahi (2022), the coupler is made with a length of approximately 54 mm. Additionally, in the research by Shokrzadeh and Nateghi-Alahi (2022), numerical testing was conducted with a variation in coupler length of 168 mm. Therefore, in this study, two length variations are used, namely 60 mm for the compact sleeve (Fig. 2a) connection, 100 mm for the long sleeve connection (Fig. 2b) and 60 mm with additional welding at both ends of the coupler (Fig. 2c). For detailed size and specimen dimensions, please refer to Fig. 3 and Table 1.

(a) (b) (c)

Figure 3. (a) compact sleeve, (b) long sleeve, (c) compact sleeve with additional welding at both ends of the coupler

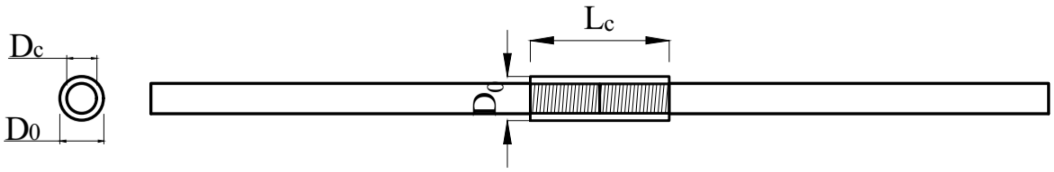


Figure 4. Test specimen.

Table 1. The dimensions of the test specimen

Specimen	**Diameter** **D_0**	**Coupler diameter** **D_c**	**Coupler length** **L_c**	**Weld**
	mm	mm	mm	-
13NC	13	-	-	-
16NC	16	-	-	-
13C19	13	19	60	-
13L19	13	19	100	-
13C19W	13	19	60	√
13C22	13	22	60	-
13L22	13	22	100	-
13C22W	13	22	60	√
16C25	16	25	60	-
16L25	16	25	100	-
16C25W	16	25	60	√

The reinforcement will be threaded with a size closest to the original diameter of the reinforcement to prevent excessive reduction in the cross-sectional area. The 13 mm diameter reinforcement will be threaded with a size equivalent to a ½ inch or 12.7 mm bolt, and the 16 mm diameter reinforcement will be threaded with a size equivalent to a 5/8 inch or 15.875 mm bolt.

The strength of the thread to be used should be calculated based on the equation described by (Alexander, 1977). The thread strength considered includes the effective area that resists tension and the shear strength of the internal thread in resisting forces.

Tensile Stress Area.

$$A_s = \frac{\pi}{4} - \left(d - \frac{0{,}9743}{n}\right)^2 \qquad (1)$$

Shear area

$$AS_s = \pi \; n \; LE \; D_1 \left(\frac{1}{2n} + 0{,}57735 \; (d_2 - D_1) \right) \qquad (2)$$

$$AS_n = \pi \; n \; LE \; d_1 \left(\frac{1}{2n} + 0{,}57735 \; (d_1 - D_2) \right) \qquad (3)$$

The thread's tensile strength and shear strength can be calculated by multiplying the area and grade. According to ASME B1.1-2003, the shear strength grade is 0.5 of the bolt grade. Therefore, it can be formulated as follows.

$$P_t = A_s \; f_s \qquad (4)$$

$$P_s = AS_s \; 0{,}5 f_s \qquad (5)$$

The testing standard used in this research is ASTM A1034 -10a, Regarding standard methods to Standard Test Methods for Testing Mechanical Splices for Steel Reinforcing Bars. The test has been done using Universal Testing Machine (UTM). According to ASTM A1034/A1034M-10a, the required loading speed ranges from 70 MPa/minute to 700 MPa/minute. In this testing, the loading speed is set at 1 kN/s, corresponding to a speed of 303.71 MPa/minute for the D16 reinforcement splice and 461.82 MPa/minute for the D13 reinforcement splice. The testing setup is depicted in Figure 4.

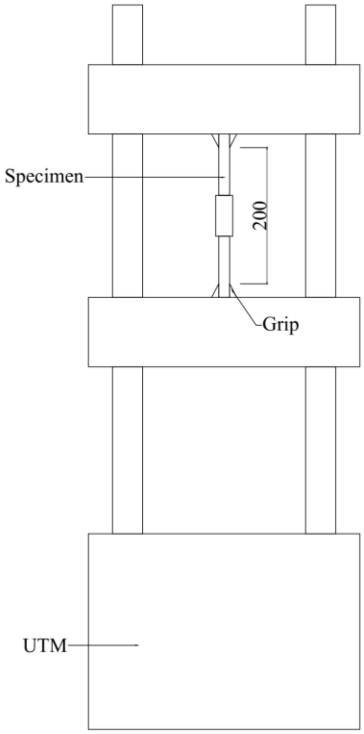


Figure 5. Test Set-up

RESULTS AND DISCUSSION

Tensile strength test results

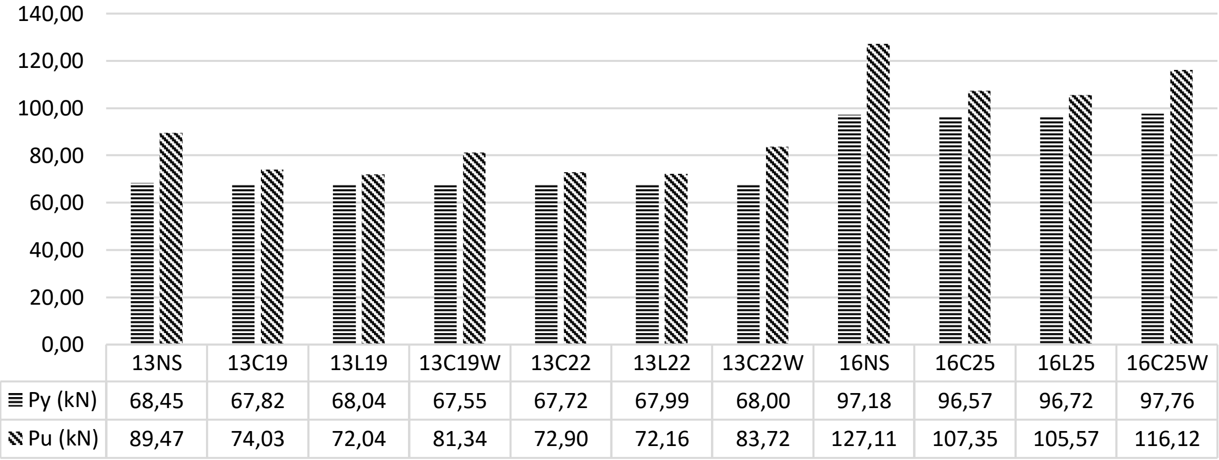
The tension test of 13 mm and 16 mm diameter reinforcement was conducted on three samples for each variation, including the intact reinforcement, reinforcement with D19 and D22 couplers for 13 mm diameter reinforcement, and reinforcement with D25 coupler for 16 mm diameter reinforcement. The diameter of the reinforcement was determined by measuring the length and weight of the intact reinforcement and calculating the average diameter using the following equation.

$$D = 12,74 \times \sqrt{\frac{w}{l}} \qquad (6)$$

Table 2. The average diameter of the D13 and D16 reinforcement bars

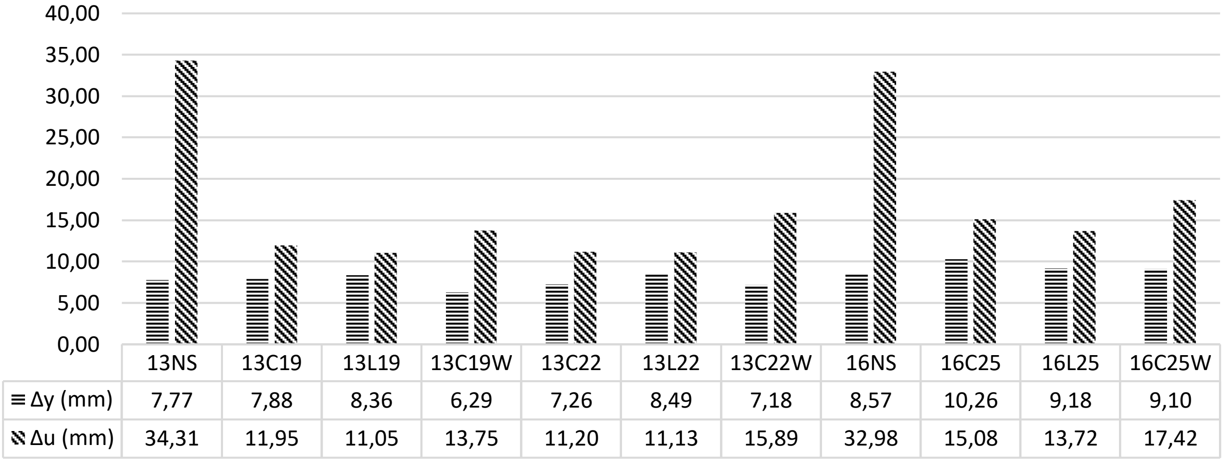
Type	**Weight** **gr**	**L** **mm**	**D** **mm**
D13	366,9	360	12,862
D16	558,6	362	15,826

The data obtained from the testing of D13 and D16 reinforcement bars include the load at yield point (Py), elongation at yield point (Δy), maximum load capacity of the reinforcement (Pu), and elongation at maximum load (Δu). The testing results are shown in Fig.4 dan Fig.5.



	13NS	13C19	13L19	13C19W	13C22	13L22	13C22W	16NS	16C25	16L25	16C25W
≡ Py (kN)	68,45	67,82	68,04	67,55	67,72	67,99	68,00	97,18	96,57	96,72	97,76
▨ Pu (kN)	89,47	74,03	72,04	81,34	72,90	72,16	83,72	127,11	107,35	105,57	116,12

Figure 6. The average load results of the tensile testing for D13 reinforcement splices at yield and maximum conditions



	13NS	13C19	13L19	13C19W	13C22	13L22	13C22W	16NS	16C25	16L25	16C25W
≡ Δy (mm)	7,77	7,88	8,36	6,29	7,26	8,49	7,18	8,57	10,26	9,18	9,10
▨ Δu (mm)	34,31	11,95	11,05	13,75	11,20	11,13	15,89	32,98	15,08	13,72	17,42

Figure 7. The average elongation results of the tensile testing for D13 reinforcement splices at yield and maximum conditions.

Based on the tensile test results, the maximum load values obtained by the D13 and D16 reinforcement bars without any splice at the yield and maximum points, respectively, are 68.453 kN and 89.47 kN for D13 and 97.177 kN and 127.108 kN for D16.

The maximum load obtained is accepted for all D13 reinforcement with coupler splices, passes through the yield point of the D13 reinforcement without any splice. However, the maximum loads cannot exceed the maximum point of the reinforcement without any splice. The difference in load at the yield point is less than 1 kN or a maximum of 1.33% for 13C19W, while the difference in load at the maximum point can reach 17.343 kN or 19.49% for 13L19.

The acceptable elongation by the D13 reinforcement bar without any splice at the yield and maximum points is 7.773 mm and 34.305 mm. However, for D13 reinforcement with coupler splices, the maximum elongation at the yield and maximum points is 8.495 mm for 13L22 and 15.892 mm for 13C22W. Adding a welded splice at the end of the coupler increases the coupler's strength by only 7.312 kN for the 19 mm coupler and 10.818 kN for the 22 mm coupler. The acceptable elongation by the splice also increased by 1.792 mm for the 19 mm coupler and 4.691 mm for the 22 mm coupler.

The load that has been received by the reinforcement D16 at yield and maximum point is 97.177 kN and 127.108 kN. At D16 reinforcement with coupler splices, the load at yield and maximum points is 97.758 kN and 116.12 kN, respectively, for 16C25W.

For all types of D16 reinforcement with coupler splices, it is found that the maximum load capacity exceeds the yield point of the D16 reinforcement without any splice. However, the maximum load is not passed the D16 reinforcement without any splice. The difference between the load at the yield and maximum conditions is only 1.041 kN or 1.07% for 16C25W. However, the load at the maximum point decreases by up to 21.539 kN or 16.95% for 16L25.

The received elongation by the D16 reinforcement without any coupler splice at the yield and maximum points is 8.568 mm and 32.98 mm, respectively. For D16 reinforcement with coupler splices, the maximum elongation at the yield and maximum points is 10.259 mm for 16C25 and 17.424 mm for 16C25W.

Adding a welded splice at the end of the coupler splice can increase the load capacity by 8.77 kN and increase elongation by 2.342 mm or 15.53% compared to the splice without the welded addition.

Stress and Strain

Gere & Timoshenko (1972) argue that stress is the action of force that is distributed continuously and work at all of the surfaces of the entire cross-section, and it can be denoted by the symbol σ (sigma). Strain is the elongation due to axial loading (ΔL) compared to the initial length (L), commonly denoted as ε. Strain is a dimensionless quantity as it represents the ratio between two lengths. Based on this definition, strain can be formulated as follows.

$$\sigma = \frac{P}{A} \tag{7}$$

$$\varepsilon = \frac{\Delta L}{L} \tag{8}$$

Table 3. The average stress and strain of D13 and D16 reinforcement bars

Type	**σy** **MPa**	**εy**	**σu** **MPa**	**εu**	**σu/σy**
13NS	526,891	0,039	688,658	0,172	1,307
13C19	521,978	0,039	569,784	0,060	1,092
13L19	523,709	0,042	554,464	0,055	1,059
13C19W	519,899	0,031	626,061	0,069	1,204
13C22	521,272	0,036	561,130	0,056	1,076
13L22	523,299	0,042	555,434	0,056	1,061
13C22W	536,880	0,036	669,297	0,079	1,247
16NS	491,910	0,043	643,392	0,165	1,308
16C25	488,800	0,051	543,384	0,075	1,112
16L25	489,578	0,046	534,369	0,069	1,091
16C25W	494,839	0,046	587,773	0,087	1,188

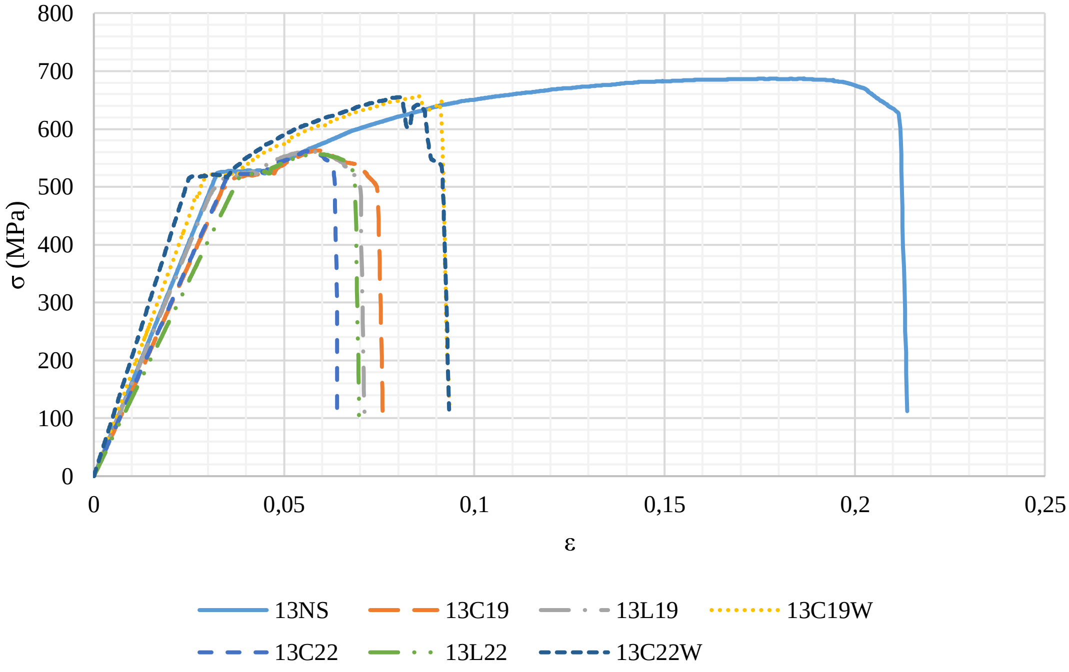


Figure 8. Stress-strain curve of D13 reinforcement splice

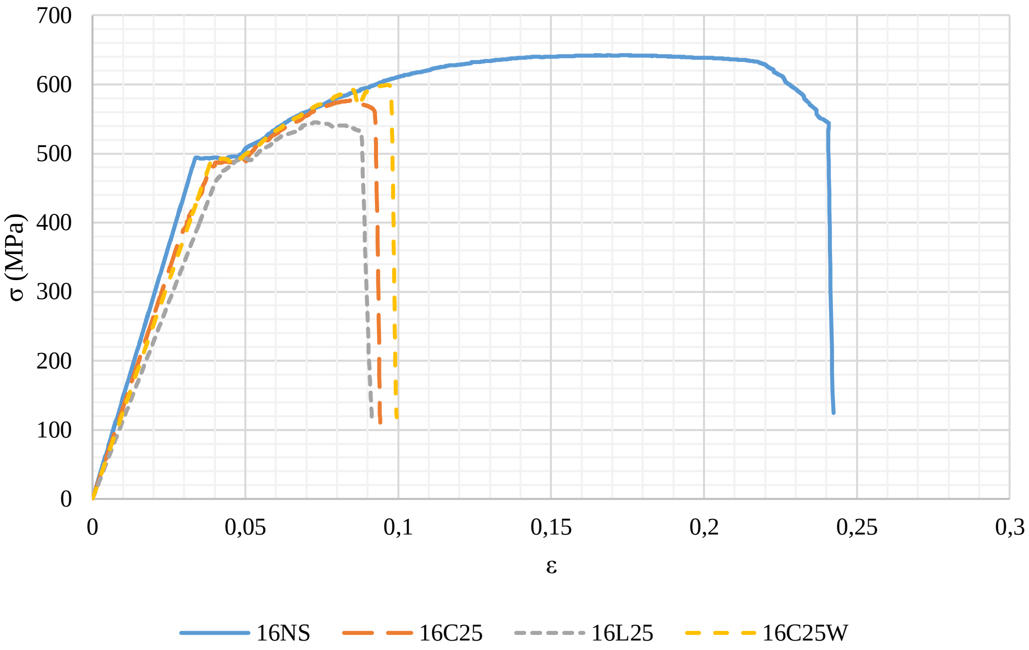


Figure 9. Stress-strain curve of D13 reinforcement splice

For both D13 and D16 reinforcement bars, both in intact and spliced conditions, the yield stress and maximum stress values achieved the requirements stated in SNI 2052:2017 for BJTS 420B, which has a minimum yield stress of 420 MPa and a maximum of 545 MPa, as well as a minimum, maximum stress of 525 MPa. However, the requirement for the stress ratio of maximum to yield stress is 1.25; it is only passed by whole reinforcement bars for D13 and D16. The stress ratio of the largest splice only reached 1.247 for 13C22W and 1.188 for 16C25W.

The yield and maximum strain for intact reinforcement are 0.039 and 0.172 for D13, and 0.043 and 0.165 for D16, respectively. For reinforcement without couplers, the strain of 200 mm has been achieved by the requirement of SNI 2025:2017 of 14%. In reinforced bars with mechanical splice, there is no maximum strain that exceeds 14% for D13 and D16. The strain at the maximum point is only 0.079 for 13C22W and 0.087 for 16C25W.

The stress-strain curve at the linear phase to the plastic phase of all the reinforcement bars has the same pattern and grade compared to the whole reinforcement bars for D13 and D16. After the reinforcement reaches the strain hardening phase, the reinforcement with coupler splices tends to the necking phase quickly. The stress-strain pattern curve has been shown by reinforcement splice with the addition of welded joints is decreased than increased. It is indicated that there is a failure at the point of welded reinforcement.

Moreover, the stress-strain graph exhibits a pattern similar to the research conducted by Shokrzadeh and Nateghi-Alahi (2022) (Fig. 2), which shows a linear phase and a melting phase resembling intact reinforcement but with differences in the strain hardening phase. However, this study obtained a longer strain hardening phase due to the thread type used, allowing for a reduction in cross-sectional area.

Ductility

Bompa & Elghazouli (2018) calculated the ductility of reinforcement splices by comparing the maximum strain obtained at maximum stress to the strain of the reinforcement at the yield point. The ductility of the reinforcement splice decreases as the length of the coupler used increases, both in direct reinforcement testing and testing of embedded reinforcement in concrete.

$$\mu = \frac{\varepsilon_u}{\varepsilon_y} \tag{9}$$

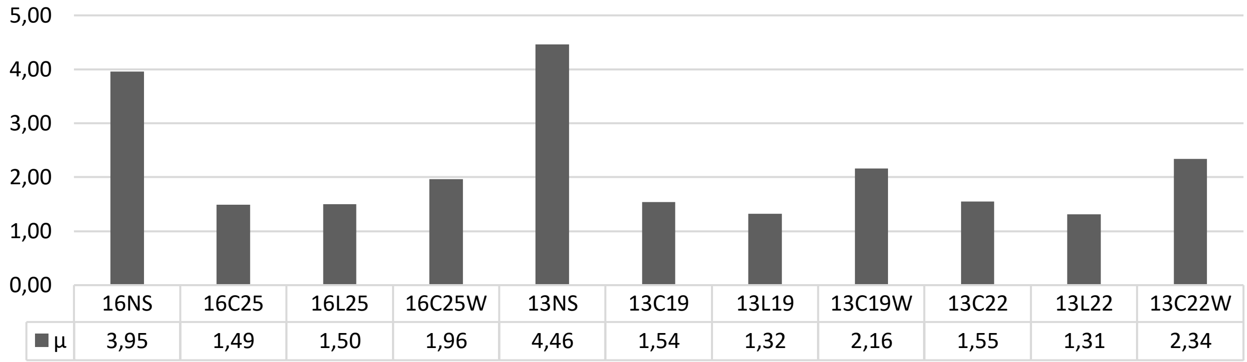


Figure 10. The comparison of the ductility of D13 and D16 reinforcement splices

The difference in ductility obtained, particularly in variations of coupler length, shows that increasing the length of the coupler led to a decrease in splice ductility. This is shown in the compact and long splice types for D13 reinforcement with 19 mm and 22 mm diameter couplers, although the difference in ductility is only around 0.213 - 0.242. However, for D16 reinforcement splices, the length of the coupler does not significantly affect ductility. Using different coupler diameters for D13 reinforcement does not affect the ductility of the splice.

Adding welds to the splice can also enhance the ductility of the connection. The ductility of D13 reinforcement splices increases by 0.622 for the 19 mm diameter coupler and 0.785 for the 22 mm diameter coupler. In the case of D16 reinforcement splices, an increase in ductility of 0.47 is observed due to the addition of welds.

The calculation results for ductility factors indicate that using a longer coupler will decrease the ductility factor achieved by the connection, in line with the study by Bompa & Elghazouli (2018). Their research states that the longer the connection type, the lower the ductility of the connection.

Failure of the Splice

All the failures that occurred in the splices, both in D13 and D16 reinforcement splices, were necking failures located in the threaded portion of the reinforcement due to the reduction in cross-sectional area. There are two types of necking failures that occur: necking until fracture (Fig. 11) and necking without reaching fracture (Fig. 12). The majority of D16 reinforcement splices have necking without reaching fracture. However, in D13 reinforcement splices, most necking resulted in a fracture. One test specimen of the D16 reinforcement splice, specifically the 16C25 type, has damage to the threads (Fig. 13). Kerusakan ulir kemungkinan diakibatkan oleh

(a) **(b)**

Figure 11. Fracture necking failure in D16 (a) and D13 (b) reinforcement bars

Figure 12. Failure did not reach fracture for D16

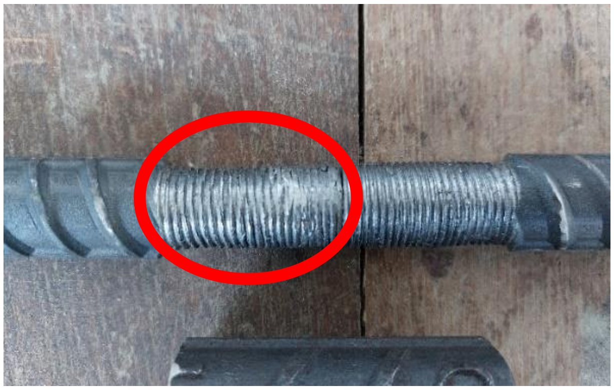


Figure 13. Damage to the thread connection

D13 reinforcement splices with welded joints at the end of the coupler, the failure that occurs is the fracture of the reinforcement located at the weld point. In D16 reinforcement splices without welded joints, the failure observed is the damage to the weld without the fracture of the reinforcement. This indicates the possibility of necking occurring inside the splice or at the threaded portion of the reinforcement.

Figure 14. Failure of welded joints in D13 and D16 reinforcement splices

CONCLUSION

Based on the research using steel reinforcement couplers, it was found that the whole all types of splices have a decrease in strength, particularly in the maximum capacity. This is due to the reduction in the cross-sectional area caused by the creation of threads. All types of mechanical splice are not qualified for the mechanical properties specified in (Badan Standarisasi Nasional, 2017). The stress-strain graph shows a similar pattern in the linear phase until reaching the plastic or yield phase. During the strain-hardening phase, spliced reinforcement exhibits a shorter phase until failure.

The application of longer couplers does not increase the strength of the splice and may decrease its ductility, as observed in D13 reinforcement splices. The addition of welds can improve the strength of the splice, but it is still not yet close to the maximum capacity of reinforcement without splices.

All failures observed in the splices were necking failures. Most failures occurred at the splice point or the location of the threaded reinforcement.

Steel reinforcement coupler splices should not be used in critical structures or structures that undergo plastic joint rotation. Further research is needed to be optimized the performance of couplers in load transfer and to meet the specified requirements.

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