- Technical Paper -

IMPROVING INSUFFICIENT INSERTION LENGTH MECHANICAL SPLICES IN RC STRUCTURES

Dac Phuong NGUYEN*1, Hiroshi MUTSUYOSHI*2 and Erina MAEDA*3

ABSTRACT

Mechanical splices are sometimes installed incorrectly in a construction site when the centers of two steel bars are deviated. As a result, the steel bars are not embedded sufficiently in a coupler. RC structures using such mechanical splices cannot achieve properties as expected. This paper develops a new recovery splice for improving such mechanical splices. The RC beams using the recovery splices showed the same load carrying capacity and crack width as the control beam without mechanical splices.

Keywords: reinforced concrete, mechanical splices, staggering length, cyclic loading,

1. INTRODUCTION

Nowadays, mechanical splices are very popular in construction of reinforced concrete structures. As a matter of fact, mechanical splices are sometimes installed incorrectly and cannot be reconstructed. For example, in the fabrication of precast RC structures, the axes of the two bars often do not align exactly and the mechanical splices cannot be assembled properly. Fig.1 shows the result of investigation of mechanical splices in construction sites by using a non-destructive ultrasonic method conducted by Japan Reinforcing Bar Joints Institute. There are 4.4% insufficient insertion length mechanical splices out of 338 splices investigated.

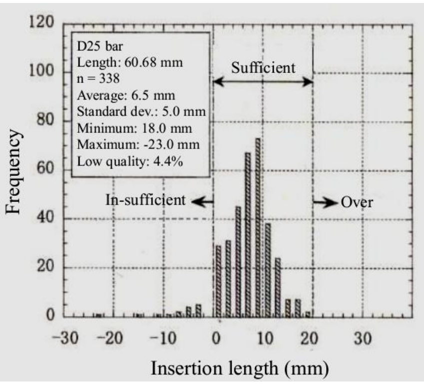


Fig.1 Investigation of low quality mechanical splices

The objective of this study is to clarify the mechanical behavior of such splices and their influence on RC structures. RC beams using mechanical splices with different insertion length of the steel bars into the couplers were prepared and tested under cyclic loading. A recovery splice for improving the low quality mechanical splices was newly developed.

2. TEST PROGRAM

2.1 Tensile test

The D19 deformed steel bars with nominal strength 345 N/mm2 (SD345) were used for all tests. The dimension of the coupler is shown in Fig.2.

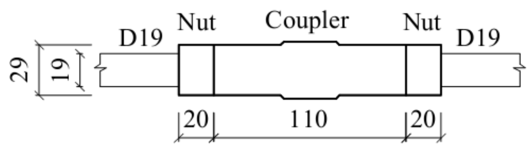


Fig.2 Mechanical splice dimension (mm)

There were three types of insertion length studied as shown in Fig.3, including two threads, three threads and six threads. Effect of epoxy injected in the mechanical splices was also studied. Table 1 shows the experimental variables.

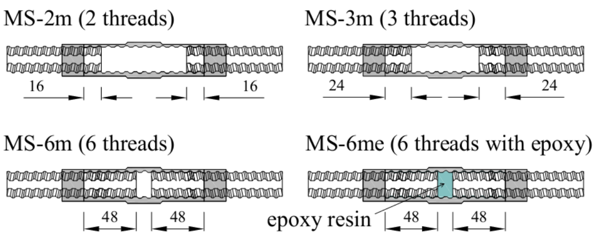


Fig.3 Quality control of mechanical splices

Table 1. Tensile test variables

Specimen	Insertion length	Epoxy injection
MS-2m	2 threads (16mm)	No
MS-3m	3 threads (24mm)	No
MS-6m	6 threads (48mm)	No
MS-6me	6 threads (48mm)	Yes

*1 PhD student, Graduate School of Science and Engineering, Saitama University, JCI Member
*2 Professor, Graduate School of Science and Engineering, Saitama University, JCI Member
*3 Master student, Graduate School of Science and Engineering, Saitama University, JCI Member

Fig. 4 shows the relationship between the stress and the apparent strain (Δ/L, Δ: deformation measured using displacements transducer over L = 180 mm including the mechanical splice).

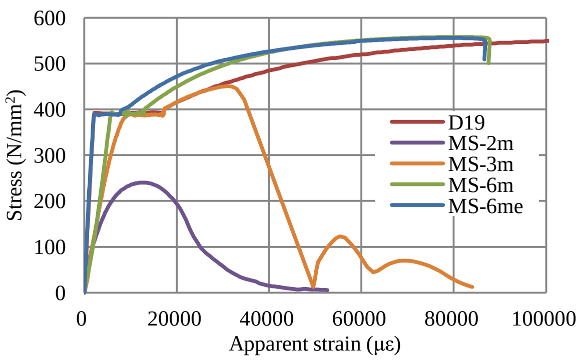


Fig.4 Tensile test results

As can be seen, insufficient insertion length mechanical splices have the lower performance on stiffness, ultimate strength as well as elongation compared to the D19 bar.

The test results are shown in Table 2. The shortest insertion length mechanical splices MS-2m have only 64% yield strength of the D19 bar and smaller stiffness than the D19 bar. Specimens MS-3m could reach the same yield strength as the D19 bar but with lower stiffness, ultimate load and elongation.

Table 2. Tensile tests results

Specimen	f_u	$f_u / f_{y(D19)}$	Failure mode
MS-2m	240	64%	Slip out
MS-3m	451	119%	Slip out
MS-6m	558	148%	Bar break
MS-6me	556	147%	Bar break

Notes: f_u = ultimate strength, N/mm^2; f_y = yield strength, N/mm^2.

Fig.5 shows the failure modes of all specimens. Failure mode of the specimens with insufficient insertion length of steel bars into the coupler (MS-2m, MS-3m) is slip out of the bar from the coupler. For the case of sufficient insertion length mechanical splices (MS-6m and MS-6me), they failed in the steel bars outside the coupler and therefore the strength at the failure showed the same one as the D19 bar. The mechanical splice MS-6m has a little lower stiffness than the D19 bar. The perfect mechanical splice MS-6me shows the same elastic modulus as the D19 bar. In spite of that, all mechanical splices show the lower elongation compared to the D19 bar because the stiffness of the coupler is much higher than that of the D19 bar.

Fig.5 Failure of mechanical splices

2.2 RC beams test

(1) Specimen

Five RC beams were prepared changing insertion length of mechanical splices. All beams were 3 m length with a span of 2.5 m and 300 mm square cross section. Fig.6 shows the dimension of the test beams. The beams were longitudinally reinforced by four D19 steel bars and transversely reinforced in the shear span by D10 stirrups with 100 mm spacing. Mechanical splices were located at the center of the span. No stirrup was used in the moment constant span in order not to disturb the crack patterns.

Electrical strain gages were used to measure the strains of reinforcement bars in the pure flexural region as well as the strains of concrete at the extreme compression surface at the mid span. Displacement transducers were used to measure the deflections of beams at the mid span and at two points of applied loads. The crack patterns were investigated and crack widths were measured along pure flexural region by using PI-shape displacement transducers. All data were recorded by using a data acquisition system.

The beams were tested cyclically. The load was applied by an actuator with a maximum capacity of 300 kN. At first, load was applied with 30 cycles for each load amplitude: 0.5Psy, 0.7Psy and 0.95Psy (Psy: calculated yield load). After yielding of the beam, the test was continued until failure.

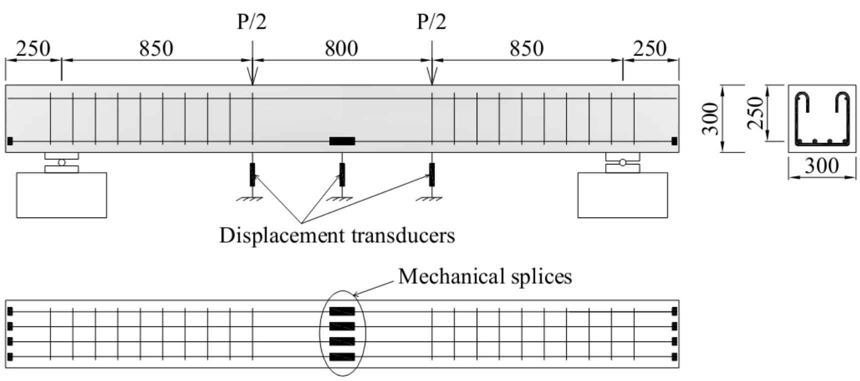


Fig.6 Beam dimensions and test set up (all measurements in mm)

(3) Test results

The tests results are discussed by focusing on load-displacement curves, failure modes and cracking behavior of the beams.

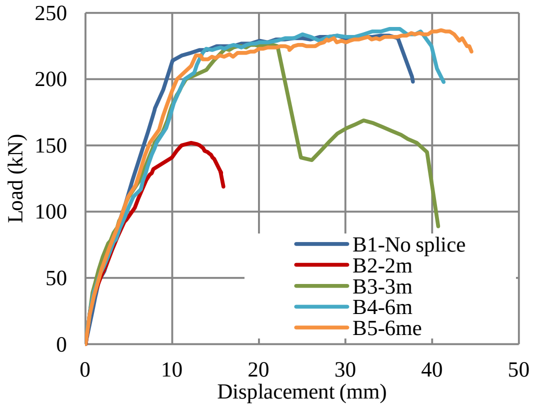


Fig.7 Load – displacement curves

Fig.7 shows the load – displacement curves of the test beams. The control beam B1 shows the typical flexural load-displacement relationship.

For the other beams using mechanical splices, when the applied load reached the cracking moment, flexural cracks occurred simultaneously at both ends of the mechanical splices due to smaller concrete cover in this region. The major flexural cracks appeared at the critical sections adjacent to the end of the mechanical splices and extended vertically by the increase of load followed by a drop in the applied load indicating a slipping of the steel bars from the mechanical splices. For further loading, number, width and extension of the cracks increased.

Behavior of the beams using sufficient insertion length mechanical splices (B4, B5) is almost the same as the control beam. They could reach the same load carrying capacity as the control beam and failed in compression after reaching almost the same displacement. Thus, it was noticed that using sufficient insertion length mechanical splices had no significant influence on the bearing capacity and ductility compared to the beam using continuous bar.

The beam using MS-3m has the same load carrying capacity as the control beam while the ultimate displacement is smaller than that of the control beam. In this beam, the slip occurred thread by thread. Firstly, the steel bars slipped out one thread pitch following by the sudden drop of load. After that the beam could bear some load before the failure.

In the beam using MS-2m, the reinforcing bars could not reach the yield strength because failure of the mechanical splices occurred prior to the yielding of the steel. The load carrying capacity of this beam is much smaller than that of the control beam. Failure mode of this beam was sudden and brittle.

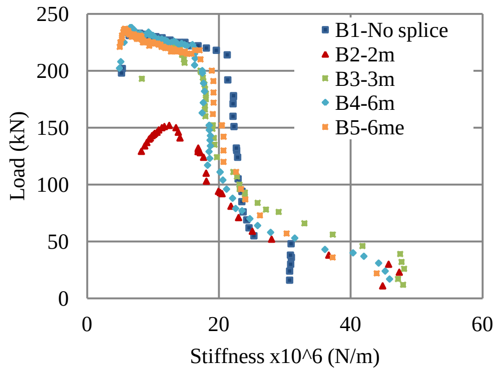


Fig.8 Stiffness of the beams

The stiffness of each beam is evaluated as the slope of the linear ascending part of the load - displacement curve. To clearly observe the stiffness of each beam, the graphs relating the stiffness with the applied load are drawn in Fig.8. It can be obviously noticed that prior to crack, the beams using mechanical splices have higher stiffness compared to the control beam. It is because of higher reinforcement ratio at the mechanical splices cross sections of the beams. Upon cracking, the stiffness of the control beam reduced slightly. Meanwhile, the beams using mechanical splices experienced distinct degradation of flexural stiffness due to the gradual slip of the steel bars from the couplers. The rate of degradation is depended on the insertion length of the bars in the couplers, in order of MS-2m, MS-3m, MS-6m, MS-6me.

Table 3 shows the test results. The failure is defined when the load reduced at 85% of max load which agrees with the 15% reduction of load carrying capacity of RC elements accepted by EC8 [3]. As checked in the tensile test, MS-2m has the strength lower than yield strength of the D19 bar and the slip out of steel bars from the coupler is the most severe. Consequently, the behavior of the beam using MS-2m was extremely brittle manner with no signs of yielding. A noticeable decrease in flexural capacity of this beams compared with the control beam was observed.

Table 3. Beam tests results

Beam	f'c	MS type	Yield		Ultimate		Failure		$P_u/P_{y(\text{control beam})}$
			P_y	d_y	P_u	d_u	P_f	d_f	
B1-4 bars	36.2	-	214	10.05	233	35.03	198	37.77	1.00
B2-2m	38.3	MS-2m	-	-	152	12.18	129	15.64	0.65
B3-3m	36.8	MS-3m	191	10.82	227	21.09	193	23.18	0.97
B4-6m	33.8	MS-6m	163	9.32	238	36.27	202	40.99	1.02
B5-6me	31.5	MS-6me	200	10.56	237	41.02	201	45.79	1.02

Notes: f'_c = compressive strength of concrete, N/mm^2; P_y, P_u, P_f = applied loads at yield, ultimate and failure, kN;d_y, d_u, d_f = displacement at yield, ultimate and failure, mm.

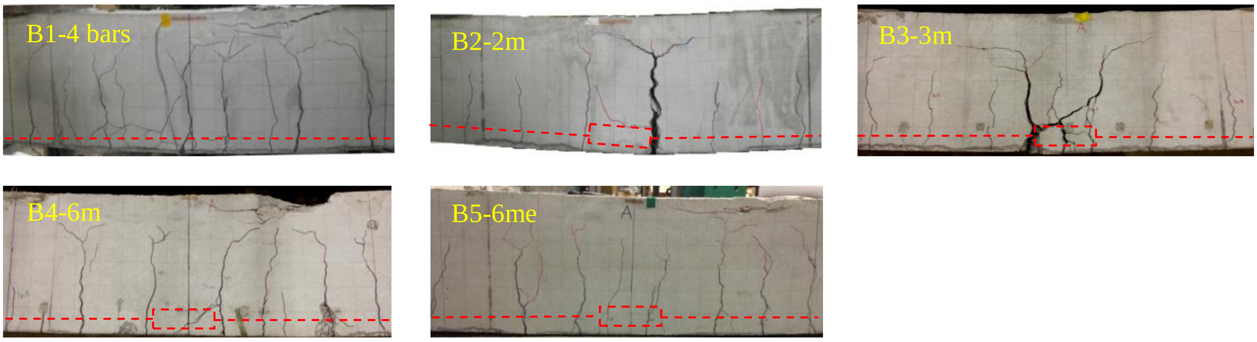


Fig.9 Crack patterns at failure of the beams

The other beams (B3, B4, B5) using mechanical splices which can reach the yield strength of the steel bar could achieve almost the same load carrying capacity as the control beam.

Fig.9 shows the pictures of the 800 mm constant moment region of the beams at failure. It can be seen clearly from these pictures that the cracks concentrate at splices location. For the beam B2-2m using MS-2m mechanical splices, the number of cracks is smaller than the control beam and the other beams using mechanical splices. The reason can be attributed to the slipping out of the steel bars from the couplers. The cracks are concentrated at one side of the mechanical splices.

After testing, the beams were broken in order to check the condition of the mechanical splices (Fig.10). The splices exhibited clear signs of slip of the steel bars from the couplers (MS-2m and MS-3m) whereas there is no slip observed in MS-6m.

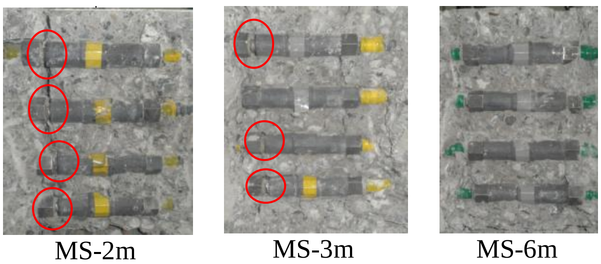


Fig.10 Slip evidence of mechanical splices

3. RECOVERY SPLICE

It was clarified from the tensile tests that mechanical splices with insufficient insertion length showed the low performance and effect on the behavior of RC beams. In order to improve such the low performance, a recovery splice was newly developed in this study. The configuration of the proposed recovery splice is shown in Fig.11. It consists of two steel semi-cylinders which can be assembled by using bolts. Outside diameter of the recovery splice is 50.8 mm and its thickness is 12 mm. For installation, the recovery splice is firstly assembled covering the mechanical splice and the steel bars, then high strength grout is filled in order to create the adhesive connection between the recovery splice and the mechanical splice as well as the steel bars. There are some grooves inside the recovery device to increase bond between the recovery splice and the grout.

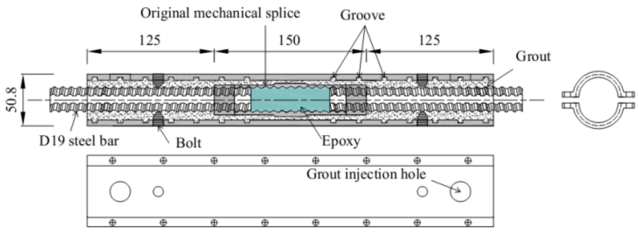


Fig.11 The newly developed recovery splice

3.1 Tensile test

(1) Specimens and set up

The recovery splice using MS-2m was prepared to check the effectiveness of the proposed recovery splice (noted as RS-2m). For comparison, the recovery splice using the steel bars without a mechanical splice with the insertion length of 200 mm was also prepared (noted as RS-200). The specimens and test set up are shown in Fig.12.

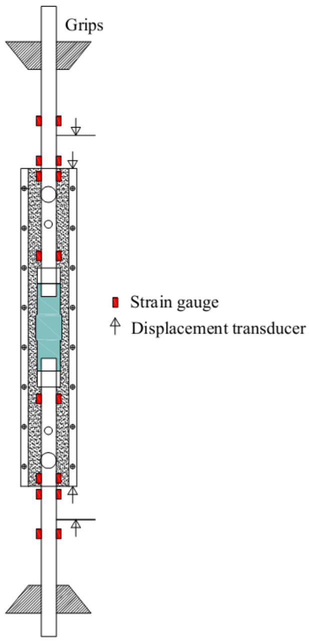
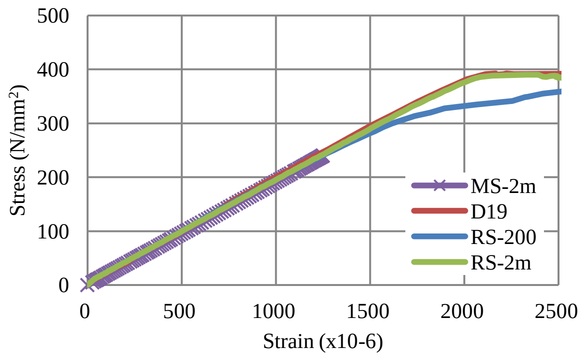


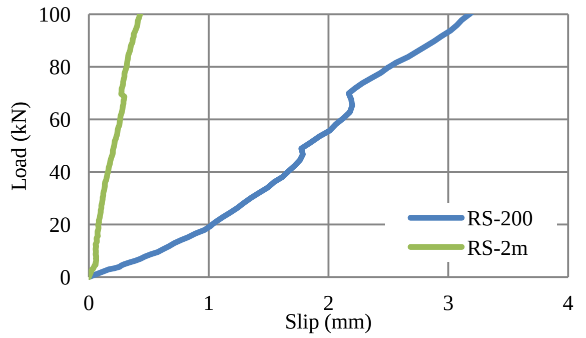
Fig.12 Tensile tests for the recovery splices

(2) Test results

Fig.13a shows the stress-strain curves of RS-2m, RS-200, MS-2m and the D19 bar. The strains are taken from the measured value of the strain gauges attached 10 mm far from the recovery splices. The insufficient insertion length mechanical splice MS-2m was improved very much by using the recovery splice. As can be seen, MS-2m could not reach the yield strength of the D19 bar meanwhile the behavior of RS-2m is almost the same as the D19 bar. For the case of RS-200 without a mechanical splice, the strain is developed with lower stiffness compared to the D19 bar. This is due to the slip occurring in RS-200 during the test. Fig.13b shows the load-slip relationship of RS-2m and RS-200. It can be observed that slip of RS-2m is very small compared to RS-200. RS-2m could reach the strength of the D19 plain bar and failed in the steel bar while RS-200 failed due to slip out of steel bars from the recovery splice. This shows the effectiveness of the recovery splice to improve the mechanical splice with insufficient insertion length.



(a) Stress – Strain curves



(b) Load – Slip curves

Fig.13 Tensile test results of the recovery splices

3.2 Beam tests

(1) Specimens

The second series of beam tests is to check the effectiveness of the proposed recovery splices in the beam. Test variables of these beams are shown in Table 4. The other components of the beams are the same as the beams in the first test series. The test set up, instrumentation and loading are the same as the previous tests.

Table 4. The second beam tests variables

Beam	f'c	Splicing type
B6-2m+6me	36.1	2 MS-2m+ 2 MS-6me
B7- r2m+6me	35.2	2 RS-2m + 2 MS-6me
B8-3 bars	30.8	-
B9-3r2m	30.7	3 RS-2m

Note: f'_c = compressive strength of concrete, N/mm².

(2) Test results

It can be seen from the load-displacement curves in Fig.14 that the beam B6 using MS-2m has very low performance. By using recovery splices, the beam B7 can reach the same capacity as the control beam. The same behavior can be observed in B9 using recovery splices compared to the beam B8 without mechanical splices. Even B9 possesses higher ductility than the beam B8.

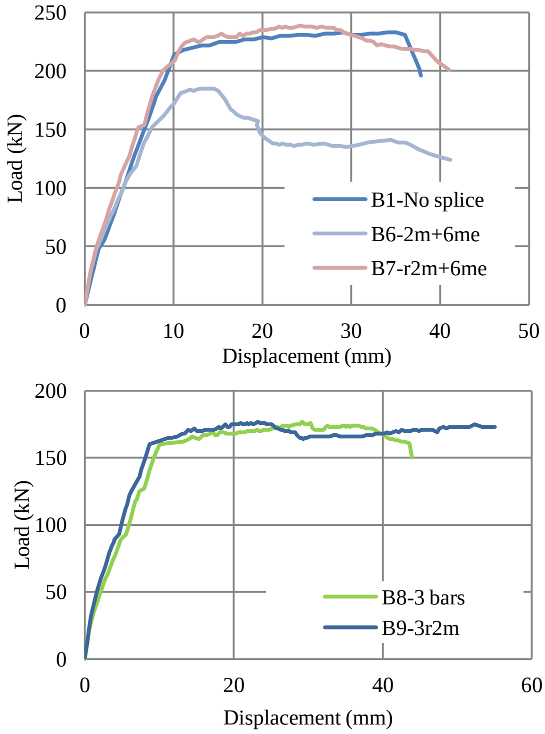


Fig.14 Load-displacement curves of the beams using recovery splices

Table 5 shows the test values at yield, ultimate and failure state. As can be seen, load carrying capacities as well as ultimate displacements of the beams using recovery splices (B7 and B9) are almost the same as the control beams without using mechanical splices.

Table 5- Results of the second beam test

Beam	Yield		Ultimate		Failure		$P_u/P_{u(control\ beam)}$
	P_y	d_y	P_u	d_u	P_f	d_f	
B6-2m+6me	169	9.62	185	14.58	157	19.49	0.79
B7-r2m+6me	209	10.13	239	24.29	203	40.62	1.03
B8-3 bars	149	9.20	177	29.21	150	43.92	1.00
B9-3r2m	150	8.11	177	23.27	173	55.05	1.00

Notes: P_y, P_u, P_f = applied loads at yield, ultimate and failure, kN; d_y, d_u, d_f = displacement at yield, ultimate and failure, mm.

4. CONCLUSIONS

Mechanical properties and effect on the behavior of RC beams of mechanical splices with insufficient insertion length were experimentally investigated. Effectiveness of the newly developed recovery splice for improving such splices was also studied. The following conclusions can be drawn from the test results:

(1) Mechanical splices with insufficient insertion length of the steel bars into the couplers failed due to slip out of the steel bars from the coupler and could not reach the ultimate strength of the steel bar as the sufficient insertion length mechanical splices did.
(2) The beams using insufficient insertion length mechanical splices have low performance both on load carrying capacity and ductility.
(3) The beams using sufficient insertion length mechanical splices have almost the same behavior as the control beam without using mechanical splices.
(4) The newly developed recovery splices can improve the mechanical properties of insufficient insertion length mechanical splice itself and RC beams.

ACKNOWLEDGEMENT

This study was carried out supported by Grant-in-Aid for Scientific Research (B). The authors would like to acknowledge members of Structural Material Laboratory of Saitama University for their support. Special appreciation is extended to Tokyo Tekko Company Ltd. for their contributions during various stages of the experimental program.

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