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EXPERIMENTAL STUDY ON SLIP COEFFICIENT OF HIGH STRENGTH BOLTED JOINT WITH METAL SPRAYED CONTACT SURFACE

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There are several ways to reduce the number of bolts of frictional bolted joints from the viewpoint of the construction cost and the maintenance cost for steel structures. For example, there are the ways which are strengthening the material of bolts, or increasing the slip coefficient. This study is focused on the slip coefficient with metal thermal sprayed contact surfaces. The objective of this study is to investigate the effects of different surface conditions on the slip coefficient. Therefore, slip tests were conducted in consideration of 9 patterns of surface treatment method (3 kinds of thickness, 3 kinds of material of sprayed metal).

Keywords: Thermal spray, High strength bolt, Frictional joint, Tensile test, Surface treatment.

1 INTRODUCTION

High strength bolted frictional joint is one of the most widely used methods for connecting steel structural members in construction sites. In recent years, it is expected to reduce the number of bolts from the viewpoint of the construction cost and the maintenance cost (Japan Society of Civil Engineers 2006).

Slip coefficient affecting the slip strength of the joints is depending on the condition of the contact surfaces, such as the roughness, the type of covered material which are painting, sprayed metal and red rust etc., and the thickness of the materials. There are many research results focusing on the slip resistance of the high strength bolted frictional joints, however, the relation between the detail condition of metal sprayed surfaces and the slip coefficient has not become clear enough.

Therefore, in this study, so as to understand the influence of the condition of sprayed metal without sealing and contact surface affecting on the slip coefficient, the tensile tests of the high strength bolted frictional joints were carried out.

In the experiments, the material of the sprayed metal, which are aluminum-magnesium (Al-Mg) alloy, zinc-aluminum (Zn-Al) alloy, and aluminum (Al), and their thickness are varied as the test parameters. Totally 9 parameters of specimens are prepared for the tensile test as shown in Table 1. Mainly discussed herein are the influence of the roughness and thickness of the surface, and the mechanical property of the sprayed materials on slip coefficient of the joints.

Table 1. Details of specimens.

Specimen	Metals	Target thickness of metal spray [µm]	Thermal sprayed method	Number of specimen and plates		
				Specimen	Splice plate	Connected plate
AM50	Al-Mg	50-120	Arc spray	3	6	6
AM100	Al-Mg	100-200	Arc spray	3	6	6
AM300	Al-Mg	300-400	Arc spray	3	6	6
AZ50	Zn-Al	50-120	Arc spray	3	6	6
AZ100	Zn-Al	100-200	Arc spray	3	6	6
AZ300	Zn-Al	300-400	Arc spray	3	6	6
AAL50	Al	50-120	Arc spray	3	6	6
AAL100	Al	100-200	Arc spray	3	6	6
AAL300	Al	300-400	Arc spray	3	6	6
Total				27	54	54

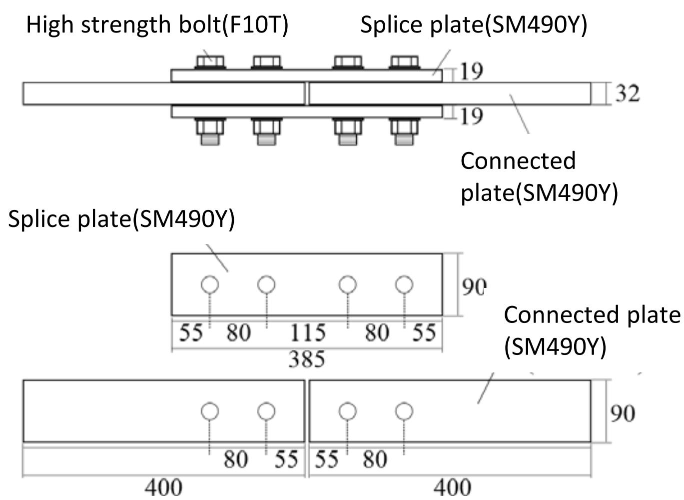

Figure 1. Configurations and dimensions of slip test specimens [unit: mm].

2 SLIP TESTS

2.1 Specimens

The configurations and dimensions of the specimens are shown in Figure 1. SM490Y steels (yielding stress: more than 355N/mm^2, tensile strength: 490~610N/mm^2) were adopted for splice and connected plates, and M22 (F10T) high strength bolts (tensile strength: 1000~1200N/mm^2, nominal diameter: 22mm) were used to connect these plates. In this study, the metals used for thermal spraying were aluminum-magnesium alloy, zinc-aluminum alloy, and aluminum. Arc sprayed method were used to the specimens.

2.2 Experimental Method

In this study, axial forces of bolts were controlled by strain gauges which were attached to two bolts on inner side of the specimen and were fastened by a torque wrench. Two outside bolts were fastened each equal torque by a torque wrench.

A universal testing machine which was able to apply a load up to 1000 kN was used for the slip test. Considering the relaxation of axial forces of the bolts, slip tests were conducted about 24 hours later after the bolts were tightened. Following quantities were measured in the test: load, relative displacement between the plates and strain of bolts. Clip-on displacement gauges were used for measuring the relative displacement.

2.3 Measuring of Thickness of Sprayed Metal

The thickness of the sprayed metal on the surfaces of the plates was measured by an electromagnetic thickness measuring machine.

20 measuring points were selected for each splice plate. 15 measuring points were selected for front and back side of each connected plate.

2.4 Measuring of Surface Roughness

The surface roughness was measured by a stylus-type surface roughness tester. Measurement positions are shown in Figure 2. The purpose of measuring of surface roughness is to consider a correlation between the surface roughness and the slip coefficient. Four measuring points were selected near each bolt hole. In this study, 6 roughness parameters were calculated, which were arithmetic average roughness Ra, maximum height Rz, 10 points average roughness Rzjis, maximum mountain height Rp, average wavelength Sm, and average gradient Δa .

2.5 Measuring of Bolt Strain for Estimating Bolt Fastening Force

Since it is difficult to measure the bolt axial force directly, the axial strains of the bolts were measured by strain gauges. In this method, it is necessity to know the relation between the bolt axial force and the strain by a bolt calibration test. In this study, two strain gauges were attached at the shank of the bolts.

And the bolt calibration tests were carried out to investigate the relationship between bolt axial force and bolt strain, and to estimate the bolt axial force by using the relationship. 6 bolts were used in the bolt calibration test as representative.

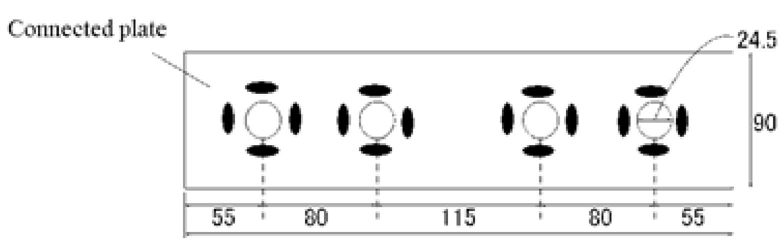

Figure 2. Example of measurement position (splice plate) [unit: mm].

3 RESULTS AND DISCUSSIONS

3.1 Measured Results of Thickness of Metal Spraying and Surface Roughness

The thickness of sprayed metal of connected plates is shown in Figure 3. As the result, the thickness of each specimen was within the target range.

The measured result of the surface roughness of the connected plates is shown in Figure 4. Each value of arithmetic average roughness Ra was increased as the thickness of metal was increased. Four roughness parameters of Ra, Rz, Rzjis, and Rp of AZ-series, were taken about half of the value in comparison with specimens of AM and AAL-series. Also roughness parameters of the splice plates were become the same tendency as the connected plates. Surface roughness of frictional joints, which the surface were shot blasted, commonly was shown the value about 14 μm for Ra, 43 μm for Rp, 90 μm for Rz, 63 μm for Rzjis. Specimens AM and AAL-series were shown almost 2 times the value compared with those surface roughness values. Specimen AZ-series was indicated as the closest value to the surface roughness of shot blasts treatment, among the 3 kinds of metal material.

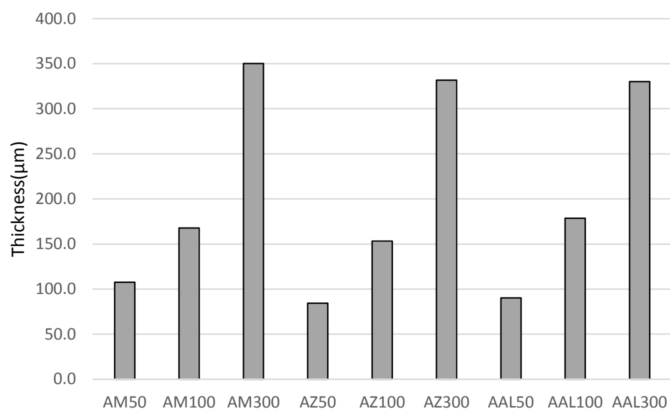

Figure 3. Average thickness of sprayed metal.

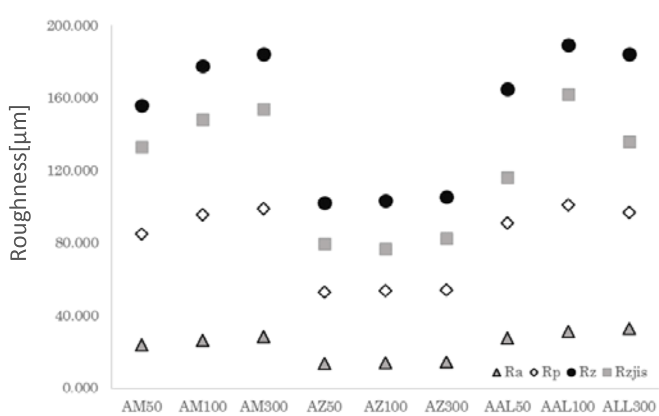

Figure 4. Roughness of contact surface.

3.2 Results of Slip Test

As the results of slip test, the peak load, bolt axial force before the test and slip coefficient are summarized in Table 2. Here, slip coefficient1 is slip coefficient, which is calculated as a designed bolt axial force. Slip coefficient2 is slip coefficient, which is calculated as a bolt axial force before slip test. And examples of relationship between load and relative displacement obtained from the slip test are shown in Figure5.

From the result, specimen of AZ-series was indicated the highest value for both slip coefficient1 and slip coefficient2 in comparison with other same thickness specimens of AAL and AM-series. Specimen of AZ-series was also shown highest value with respect to the peak load. The slip coefficients of all specimens were measured as high value, and it was found that the value was more than twice value compared with the design value (0.4-0.45) defined by the specifications for highway bridges (Japan Road Association 2012).

Table 2. Result of slip test.

Specimen	Peak load (kN)	Axial force (kN)	Slip coefficient1	Slip coefficient2
AM50	837.2	228.2	1.021	0.901
AM100	861.0	238.1	1.050	0.890
AM300	837.0	242.8	1.021	0.859
AZ50	865.1	237.1	1.043	0.909
AZ100	890.2	215.8	1.086	0.990
AZ300	892.4	225.5	1.088	0.981
AAL50	858.0	211.8	1.046	1.005
AAL100	826.8	223.4	1.008	0.932
AAL300	826.4	231.3	1.008	0.881

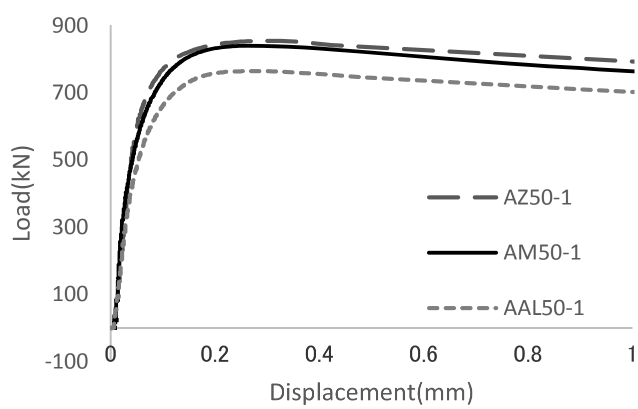

Figure 5. Examples of relationship between load and displacement.

3.3 Relationship between Slip Coefficients and Surface Conditions

The correlation coefficients between slip coefficients and surface roughness parameters are shown in Table 3. And relationship between slip coefficient and Rzjis is shown in Figure 6. It shows negative correlations in any surface roughness parameters, and Rzjis shows the largest amount of negative correlation. It can also be shown that the slip coefficient is little influenced on the roughness and thickness, and the slip coefficient could be influenced on the mechanical property such as shear strength of the material, the contact area and the porosity of the sprayed metal.

Table 3. Correlation coefficients between slip coefficient and surface roughness parameters.

Correlations	Ra	Rp	Rz	Rzjis
Slip coefficient	-0.736	-0.774	-0.782	-0809

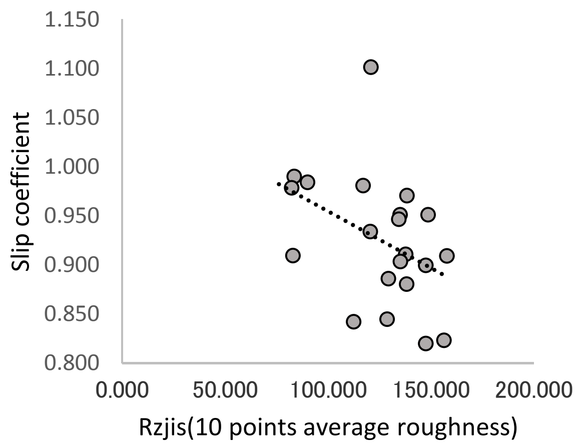

Figure 6. Relationship between slip coefficient and Rzjis.

4 CONCLUSIONS

In this study, slip tests were conducted to steel plates connected by high strength bolts as frictional joints with the contact surface with different sprayed metal treatment without sealing. The slip tests showed that the slip coefficient of the joint was a high value.

For future works, more detailed experimental study will be needed to clarify the mechanism of slip of the joint. Also, the study will need to consider durability of the metal sprayed frictional joint without sealing on contact surfaces.

References

Japan Society of Civil Engineers (2006) *Recommendations on Design, Construction and Maintenance for Friction Type of High Strength Connection.*

Japan Road Association (2012), *Highway Bridge Design Specifications.*