Resilient Structures and Sustainable Construction
Edited by Pellicer, E., Adam, J. M., Yepes, V., Singh, A., and Yazdani, S.

ISBN: 978-0-9960437-4-8

SLIP COEFFICIENT OF BOLTED SLIP-CRITICAL CONNECTIONS

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The design philosophy of slip-critical connections is to utilize the friction force developed through the clamping force exerted by the pretension of the high-strength bolt. Therefore, the slip-critical connections can have resistance in the direction of the bolt shear. This resistance is affected by the bolt clamping force and slip coefficient on the faying surfaces. This research aims to increase the resistance of the slip-critical connections. Increasing the resistance of the slip-critical connections can be achieved by increasing either the clamping force or the slip coefficient. Thermal spray coating technology was used to increase the slip coefficient. Tests were conducted to investigate the effects of coated material (aluminum or aluminum-magnesium) and coating thickness. Compared to the blast-cleaned faying surface, thermal sprayed coating faying surface results in a greater slip coefficient.

Keywords: Slip resistance, Thermal spray, Coating, Faying surface.

1 INTRODUCTION

The bolted connections are generally used in the joint of the steel members. There are two types of the bolted connections, bearing-type and slip-critical connections. The slip-critical connections are designed to not slip in service by friction on the faying surface. Therefore, the slip resistance of the connection is attributed to the clamping force which is exerted by the pretensioned bolt. The slip resistance depends on the clamping force, slip coefficient on the faying surface, number of bolts, and number of the faying surface. For the clamping force, a minimum preload of the bolt is specified in Research Council on Structural Connections (RCSC) (2009). The slip coefficient is a characteristic on the faying surfaces and can only be determined by the test. The mean slip coefficients recommended by American Institute of Steel Construction (AISC) (2010) specifications are 0.30 and 0.50 for Class A and B surface, respectively. Class A surface is the unpainted clean mill scale steel surface, while the Class B surface is the unpainted blast-cleaned steel surface.

Slip resistance had been intensively studied and documented in the literature (Kulak *et al.* 2001). Various coating materials and thicknesses were also explored in the tests. Surface preparation, such as blast-cleaned and metallized, had been investigated. The effect of surface treatment and coating material on the slip coefficient had been studied by Nah *et al*. (2009). The influence of the coating material, such as zine-based coating, on the slip coefficient had been tested by Annan and Chiza (2013). Moreover, the coating thickness needs to be inspected per SSPC (SSPC 1991, SSPC 1993).

Increasing the slip coefficient can result in the increase of the slip resistance and, further, lead to the decrease of the number of bolts and entire joint dimension. This paper aims to increase the slip coefficient by means of thermal sprayed coating. Slip tests were conducted to explore the slip coefficient. The main variables affected the slip coefficient are the surface treatment, coating material, and coating thickness.

2 TEST PROGRAM

A short-term static test was conducted to determine the slip coefficient of slip-critical connections with aluminum-based coating on the splice plates.

2.1 Test Specimens

The test specimens were designed as shown in Figure 1. The end of this butt joint with two bolts was assumed to be a fixed end, while the other end with only one bolt was expected to be slipped. The material property of the main and splice plates is confirmed to SM490B steel. The specified tensile strength of the SM490B steel is 490 N/mm^2. High-strength bolts of F10T (M20) were used to provide the clamping force for the connection.

To increase the slip coefficient, faying surfaces were thermal sprayed coating. The thermal spray coating technology is to spray powder or wire coating materials to the base material by electric arc at elevated temperature. In the steel industry, the thermal spray coating technology had been utilized in the corrosion protection. The sprayed coating material can be metal, alloy, ceramic or polymer.

Table 1 tabulates the specimen details, including coating material and coating thickness. Each set of the specimens consists of two specimens. Coating materials are either pure aluminum or aluminum-magnesium alloy. The aluminum-magnesium alloy consists of 95% of the aluminum and 5% of the magnesium. Three different coating thicknesses, 150, 300 and 450 μm, were varied in the specimens. Before the thermal sprayed coating, all the surface of the splice plates was blast-cleaned to confirm Sa $2^1/_2$. Thermal sprayed coating was performed only on the inside surface of the splice plate as illustrated in Figure 1. The average coating thickness was determined in accordance with SSPC. A total of 15 readings, three reading at five spots, was recorded on each thermal sprayed coating plate.

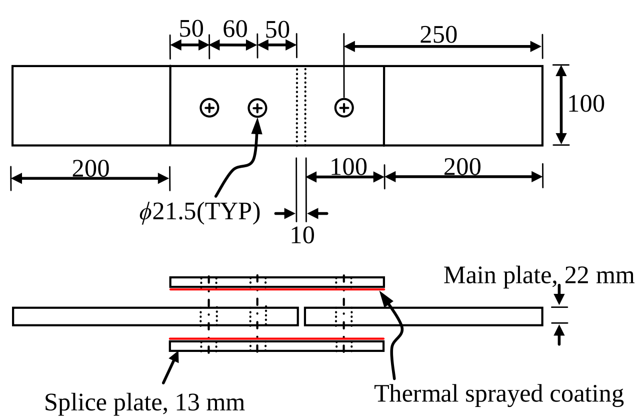

Figure 1. Details of the specimen.

Figure 2. Tension test setup.

2.2 Test Setup and Procedure

Slip tests were conducted in accordance with Research Council on Structural Connections (RCSC) (2009) which defines the slip load and determination of the slip coefficient. The test setup is presented in Figure 2, and the test specimens and results are shown in Table 1. The test specimens were installed in a hydraulic test machine. The slip load is defined as the maximum load if a maximum load occurs before a slip of 0.02 in. The slip coefficient is calculated as the ratio of the slip load to the product of the bolt clamping force and number of the faying surface. Therefore, the bolt clamping force and the slip are crucial to calculate the slip coefficient.

Optical measurement system was utilized to obtain the relative displacement, i.e. the slip, occurred between the main and splice plates. To accurate measure the bolt clamping force, all the high-strength bolts were calibrated to obtain the relations between pretension and tensile strain. To measure the tensile strain of the high-strength bolt, a bolt gauge was installed inside a hole drilled on the bolt.

Table 1. Test specimens and test results.

Specimen set	Thermal sprayed coating	Average slip coefficient
Blast-cleaned	-	0.46
Al-150	Aluminum, 150 μm	0.70
Al-300	Aluminum, 300 μm	0.66
Al-450	Aluminum, 450 μm	0.61
Al-Mg-150	Aluminum-Magnesium, 150 μm	0.72
Al-Mg-300	Aluminum-Magnesium, 300 μm	0.67
Al-Mg-450	Aluminum-Magnesium, 450 μm	0.64

3 TEST RESULTS AND DISCUSSION

The specimens behaved linear elastic at the beginning stage of the slip test. Afterward, succeeding nonlinear behavior revealed that micro slips might develop on the faying surface. A sudden slip occurred after the specimens reached the maximum slip resistance and the load dropped significantly. Figure 3 shows the appearance of the faying surface after test. During the test, the clamping forces were monitored and in the range of 143.5 to 178.6 kN.

The behavior of the specimens subjected to slip test can be demonstrated in the load-displacement curve. Typical load-slip curves are presented in Figure 4. As shown in Figure 4(a), the blast-cleaned specimens had the largest connection stiffness within the linear behavior. Due to the lesser hardness of the aluminum coating, the coated specimens had less connection stiffness compared to the uncoated blast-cleaned specimens.

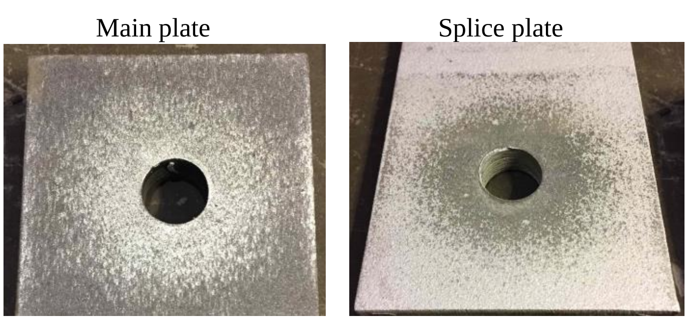

Figure 3. Appearance of faying surface of Spec. Al-450 after test.

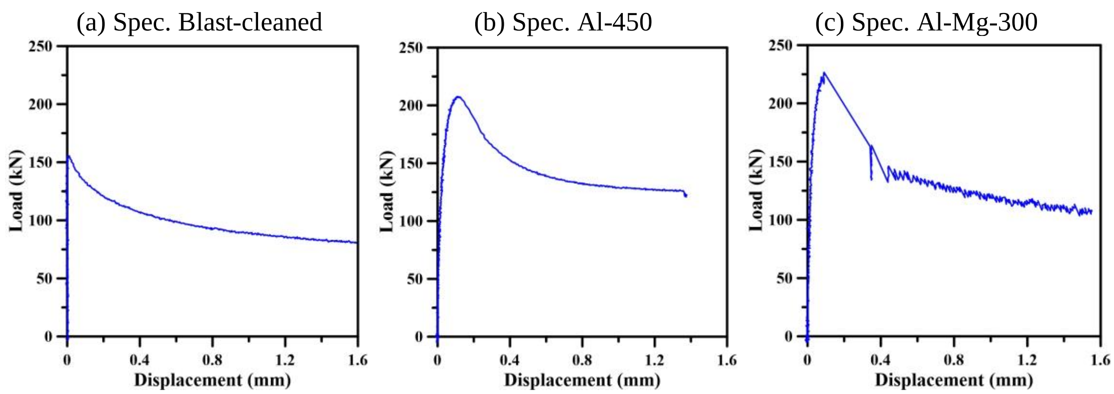

Figure 4. Load versus displacement curves.

Test results indicated that the slip loads were 142.5 and 155.5 kN for blast-cleaned specimens. For coated specimens, the slip loads ranged from 182.0 to 236.9 kN. The calculated slip coefficients are tabulated in Table 1. The blast-cleaned specimens had an average slip coefficient of 0.46 which is less than the 0.5 recommended by American Institute of Steel Construction (AISC) (2010). The slip coefficients of the Al-series specimens ranged from 0.57 to 0.71, while those of Al-Mg-series specimens were from 0.63 to 0.74. Figure 5 shows the distributions of the slip coefficients for coated specimens. It revealed that increasing the coating thickness will decrease the slip coefficient.

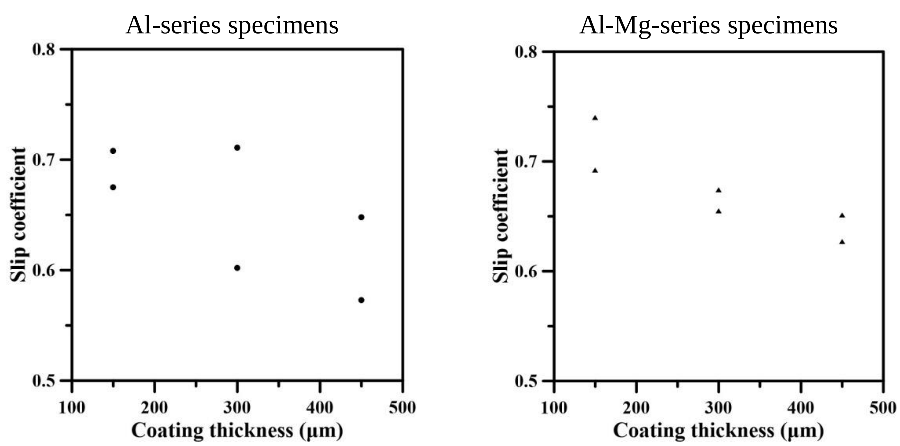

Figure 5. Slip coefficients of coated specimens.

4 CONCLUSIONS

Slip tests were conducted to explore the slip resistance of butt joins with different treatment on the faying surfaces. The conclusions have been drawn in the following:

1. The uncoated blast-cleaned faying surface developed an average slip coefficient of 0.46.
2. Thermal sprayed coating with either pure aluminum or aluminum-magnesium alloy on the faying surfaces resulted in a higher slip coefficient than the uncoated blast-cleaned faying surface.

3. The slip coefficients of the coated flaying surface with aluminum-magnesium alloy were higher than those of the coated faying surface with pure aluminum.
4. For coated faying surface, greater coating thickness generally leads to less slip coefficient.

Acknowledgments

The authors would like to thank the National Center for Research on Earthquake Engineering and the Ministry of Science and Technology of the Republic of China, Taiwan for financially supporting this research.

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