American Galvanizers Association

Status of Research on Slip Coefficient of Bolted Galvanized Steel

RCSC 2009 *Specification for Structural Joints Using High-Strength Bolts*

- Class A = 0.33 (uncoated clean mill scale steel; surfaces with Class A coatings on blast-cleaned steel)
- Class B = 0.50 (uncoated blast-cleaned steel; surfaces with Class B coatings on blast-cleaned steel)
- Class C = 0.35 (roughened hot-dip galvanized surfaces)

AISC 2010 *Specification for Structural Steel Buildings*
Slip Coefficient

- Class A = 0.30 (unpainted clean mill scale steel surfaces; surfaces with Class A coatings on blast-cleaned steel; hot-dip galvanized and roughened surfaces)
- Class B = 0.50 (unpainted blast-cleaned steel surfaces; surfaces with Class B coatings on blast-cleaned steel)

AGA Slip Coefficient Research Overview

- Multiple galvanizing baths tested
- Multiple roughening methods used
- Multiple types of surface roughness measurements taken
- One technician used for preparing plates
- One test lab used for slip coefficient testing (CCC&L)

Phase 1 Research Overview

- Six galvanizing baths chosen from galvanizers across the United States
- Galvanizers were purposely chosen with differences in galvanizing bath chemistry (grade of zinc, additives)
- Galvanized coating thickness measurements taken
- RT surface roughness measurements taken around the hole in each plate

Phase 1 Research

Comments about test plates:

- Prepared according to A2.1 from Appendix A of RCSC *Specification for Structural Joints Using High-Strength Bolts* (2009)
- Some plates had a bright and shiny galvanized coating while others had a matte gray finish
- Three test sets used from each galvanizing bath (each galvanizer was given nine plates)

Phase 1 Research

Slip coefficient averages of the six galvanizing baths:

Galvanizer A: 0.31

Galvanizer B: 0.33

Galvanizer C: 0.35

Galvanizer D: 0.36

Galvanizer E: 0.58

Galvanizer F: 0.20

Phase 1 Research

Relation (or lack thereof) between galvanized coating thickness and slip coefficient

Galvanizer	Average Galvanized Coating Thickness (mils)	Slip Coefficient Average
B	4.9	0.33
F	5.5	0.20
C	5.9	0.35
E	7.3	0.58
D	9.2	0.36
A	12.7	0.31

Phase 1 Research

RT Surface Roughness:

The distance between the highest peak and the lowest valley within any given evaluation length (ASTM D7127).

Used Mitutoyo SJ-201 profilometer to take roughness measurements.

Phase 1 Research

Relation (or lack thereof) between RT surface roughness and slip coefficient

Galvanizer	Average RT (microns)	Slip Coefficient Average
D	16.20	0.36
A	18.31	0.31
F	21.92	0.20
E	27.06	0.58
B	31.42	0.33
C	31.54	0.35

Phase 1 Research Summary

- Galvanizing bath chemistry does not seem to be a primary determinant of slip coefficient
- Five out of the six galvanizing baths tested had a slip coefficient greater than 0.30
- Galvanized coating thickness does not seem to correlate with slip coefficient
- RT surface roughness does not seem to correlate with slip coefficient

Phase 2 Research Overview

- Galvanizing bath that had the lowest slip coefficient (0.20) from Phase 1 testing used to galvanize all plates
- The galvanized coating was prepared using one of four different methods
- A Class B zinc-rich epoxy coating was applied over the prepared galvanized coating
- Same plates used in Phase 1 testing used (after stripping and re-galvanizing)

Phase 2 Research

The galvanizing bath with the lowest slip coefficient from Phase 1 testing was used to start using the worst case scenario and then improve from there.

Phase 2 Research

Four different preparation methods used to prepare the galvanized coating prior to application of the zinc-rich epoxy:

- Wire brush
- Galvaprep 5
- Picklex 20
- Hand sanding block with 80-grit sandpaper

Phase 2 Research

RT surface roughness measurements after application of the zinc-rich epoxy over the prepared plates (values listed in microns):

Wire brush	15.63
Galvaprep 5	13.9
Picklex 20	15.51
Sanding block	13.45

Phase 2 Research

Slip coefficient averages of prepared and zinc-rich epoxy coated plates

Preparation Method	Slip Coefficient Average
As galvanized (control)	0.29
Wire Brush	0.25
Galvaprep 5	0.26
Picklex 20	0.30
Sanding Block	0.39

Phase 2 Research

Averages of individual plates sets (shows variation)

Preparation Method	Slip Coefficient Average	Slip Coefficient Sample Set 1	Slip Coefficent Sample Set 2	Slip Coefficient Sample Set 3
As galvanized (control)	0.29	0.32	0.32	0.24
Wire Brush	0.25	0.07	0.27	0.41
Galvaprep 5	0.26	0.44	0.19	0.15
Picklex 20	0.30	0.35	0.11	0.43
Sanding Block	0.39	0.42	0.38	0.38

Phase 2 Research Summary

- The slip coefficient of the unprepared galvanized plates (control) was higher than in Phase 1 testing (0.29 versus 0.20)
- Was not able to achieve a Class B slip coefficient using this particular zinc-rich epoxy coating
- Some preparation methods showed a wide range in slip coefficient values

Phase 3 Research Overview

- Galvanizing bath that had the lowest slip coefficient (0.20) from Phase 1 testing used to galvanize all plates
- Galvanized coating was roughened with a hand sanding block and 80-grit sandpaper
- Nine different Class B coatings from four paint manufacturers were applied over roughened galvanized steel
- Same plates used in Phase 2 testing used (after stripping and re-galvanizing)
- Only one test set (3 plates) were used for each test
- Additional types of surface roughness measurements were taken

Phase 3 Research

Roughening procedure of the galvanized coating prior to Class B coating application:

- Hand sanding block
- 80-grit sandpaper
- Fresh sandpaper was used for each set of test plates (changed after every 3 plates)
- The plates were sanded with a circular motion with pressure hard enough to leave visible marks in the galvanized coating

Phase 3 Research

Additional surface roughness measurement definitions (from profilometer manual)

- Ra: arithmetic mean of the absolute values of the profile deviations from the mean line
- Rq: square root of the arithmetic mean of the square of profile deviations from the mean line (root-mean-square deviation)

Used SJ-201 profilometer to take roughness measurements.

Phase 3 Research

Class B Coating	Slip Coefficient	Average Rt (mils)	Average Ra (mils)	Average Rq (mils)
1	0.45	1.47	0.19	0.35
2	0.48	0.96	0.13	0.16
3	0.48	1.33	0.19	0.24
4	0.39	1.17	0.15	0.19
5	0.48	1.71	0.24	0.29
6	0.53	0.58	0.09	0.1
7	0.23	1.77	0.24	0.3
8	0.44	1.97	0.26	0.32
9	0.55	1.14	0.14	0.18
Control (no paint)	0.34	1.26	0.17	0.21

Phase 3 Research Summary

- Two coatings applied over the roughened galvanized coating achieved a Class B slip coefficient
- Five other coatings achieved slip coefficients close to Class B
- Because only one test set (3 plates) was used for each test, repeatability was not tested
- Ra and Rq surface roughness measurements do not seem to correlate with slip coefficient

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