COLLEGE OF ENGINEERING
DEPARTMENT OF CIVIL ENGINEERING (CVEG)
STEEL STRUCTURES RESEARCH LABORATORY (SSRL)

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Materials Testing Report:

Automated Pin-Dot Marking Effects on A709-Gr50 Steel Plate Fatigue Capacity

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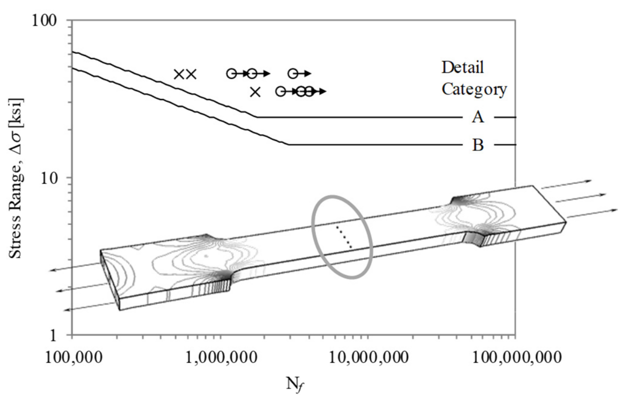

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Automated Pin-Dot Marking Effects on A709-Gr50 Steel Plate Fatigue Capacity

Mandate:	W&W | AFCO Steel
Mandate Description:	Experimental characterization A709-Gr50 steel fatigue capacity following automated pin-dot marking of the plate surface. Comparison of results with existing AASHTO fatigue detail categories to determine compliance with AREMA specifications.
Date of Mandate:	September, 2016
Specimens:	10 steel coupon specimens representing low and high marking frequencies and different plate rolling orientations (transverse and longitudinal).
Reception of the Specimens:	August 24, 2016
Testing Dates:	August 2016 – September 2016
Project PI:	G.S. Prinz
Collaborators:	D. Noernberg
Report Author(s):	G.S. Prinz, M. Noernberg
SSRL Director:	G.S. Prinz

Signatures:

Project PI

Gary S. Prinz, PhD, PE

This report contains 6 pages

REPORT DISCLAIMER

The conclusions presented in this report are the result of a study conducted in the Steel Structures Research Laboratory (SSRL) at the University of Arkansas and reflect the expert opinions of the report authors only.

MATERIALS TESTING REPORT

1. Introduction

1.1. *Background*

During fabrication of multi-piece steel assemblies, markings are often made on the steel surface to identify/track individual pieces or to provide reference for later erection. While these markings can be made by various manual methods (crayons, tags, die stamps, etc.) automated marking methods offer potential fabrication efficiencies by creating rapid computer controlled indentations in the steel surface.

For marked steel sections subjected to frequent or repeated loading (i.e. bridge girders, machinery components, etc.) surface indentations from these automated markings have the potential to affect component fatigue capacity. To account for marking effects, specifications often require additional experimental verification to ensure adequate fatigue performance. In the American Railway Engineering and Maintenance-of-Way Association (AREMA) manual for railway engineering [1], piece marking methods that create an indentation on the steel surface must be demonstrated by testing to meet Fatigue Category B in the AASHTO LRFD Bridge Design Specification [2].

In AASHTO, the design load-induced fatigue resistance for detail category B takes the form:

$$(\Delta F)_n = \left(\frac{120\times10^8}{N}\right)^{\frac{1}{3}} \geq 16\,ksi \qquad \text{(Eq. 1)}$$

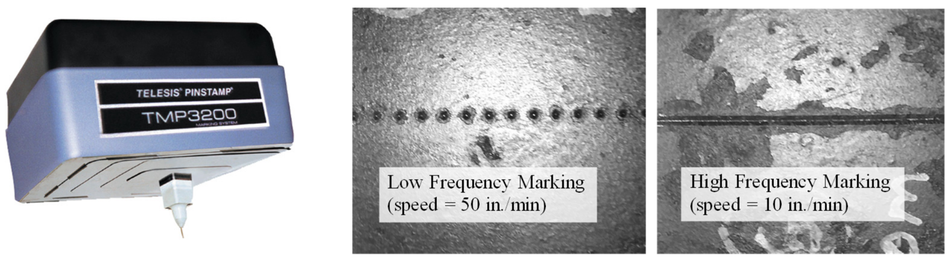
where $(\Delta F)_n$ is the allowable applied stress range and N is the number of cycles to fatigue failure. In order to satisfy compliance as a Fatigue Category B detail, fatigue tests must indicate a capacity greater than that provided by Equation 1.

Recent research efforts into the effects of automated piece-marking methods on plate fatigue capacities indicate no difference between marked and unmarked plate sections [3,4]. In one study by [3] a total of 10 material coupons containing alphanumeric characters were fatigue tested, resulting in only 2 failures (which occurred at fatigue capacities expected for unmarked plate, fatigue detail category A) and 8 runouts ranging from between 2.6 million and 9.3 million cycles. While the results from the marking systems described in [3,4] indicate negligible fatigue effects, because certain features of these automated marking systems can change between manufacturer (marking depth, frequency, indenter type, etc.) each marking system must be verified prior to implementation in fatigue prone applications covered by the AREMA guidlines.

This research study investigates the Telesis TMP3200/470 automated marking system for compliance with the AREMA fatigue requirements. To quantify effects of marking frequency on steel plate fatigue capacity, two levels of marking frequency are investigated. These marking frequencies represent the upper and lower bound capabilities of the Telesis TMP3200/470 marking system. The study begins with a brief overview of the Telesis TMP3200/470 marking system, followed by a description of the specimen fabrication and testing methods. Next, results from the fatigue testing are discussed and conclusions are presented.

1.2. *Overview of the Telesis TMP3200/470 Marking System used by W&W | AFCO Steel*

Figure 1(a) shows the marking head of the Telesis TMP3200/470 and Figure 1(b) shows an A709-Gr50 steel plate sample with two marking dot frequencies corresponding to the upper and lower bound dot-frequency capabilities of the system. The automated Telesis TMP3200/470 system uses a single marking pin, which depending on the pin size can create indentation depths of between 0.001” and 0.018”. In addition to variable marking depth, the pin-dot system can vary marking frequency, up to 200 dots-per-inch, forming seemingly continuous indentation marks in the steel surface (see Figure 1(b)).



(a) (b)

Figure 1. (a) Telesis TMP3200/470 marking head and (b) marked steel surface

2. Specimen Fabrication and Testing Methods

To investigate the effects of the Telesis TMP3200/470 pin-dot marking system on the fatigue capacity of A709-Gr50 steel plate, a total of 10 coupon specimens representing 2 marking frequencies (50in./min and 10in./min), 2 applied stress ranges (35ksi and 45ksi), and 2 material orientations (both longitudinal and transverse plate rolling directions) were fatigue tested. Figure 2(a) shows the coupon specimen geometry, which was chosen to satisfy the ASTM A370-16 specification for mechanical testing of steel products [5]. To ensure consistent pin-dot marking between each specimen, marking lines were scribed in a piece of ½” A709-Gr50 steel plate prior to the plasma cutting of each coupon (see Figure 2(b)). As shown in Figure 2(b), a total of 4 lines were scribed in the plate prior to fabrication of the coupon specimens; accounting for both transverse and longitudinal plate rolling directions as well as the highest and lowest pin-dot marking frequencies possible in the Telesis TMP3200/470 marking system to bound any marking effects. In addition to the marked specimens, four additional un-marked material coupons were fabricated and fatigue tested to allow comparison.

All specimens were fatigue tested in a Walter+Bai servo-hydraulic bi-axial fatigue testing machine under uni-directional loading, resulting in an applied mean stress equal to half of the applied stress range. To reduce the required testing time, a loading rate of 20Hz was used for each test specimen. Note that the two applied stress ranges of 35ksi and 45ksi were chosen to allow comparison with the finite-life fatigue capacities from the AASHTO A and B fatigue detail categories [2].

Table 1 shows the fatigue test matrix describing specimen material orientation, marking frequency, loading rate, and the resulting fatigue capacity. All fatigue capacities presented in Table 1 will be discussed in detail in the following Fatigue Test Results section.

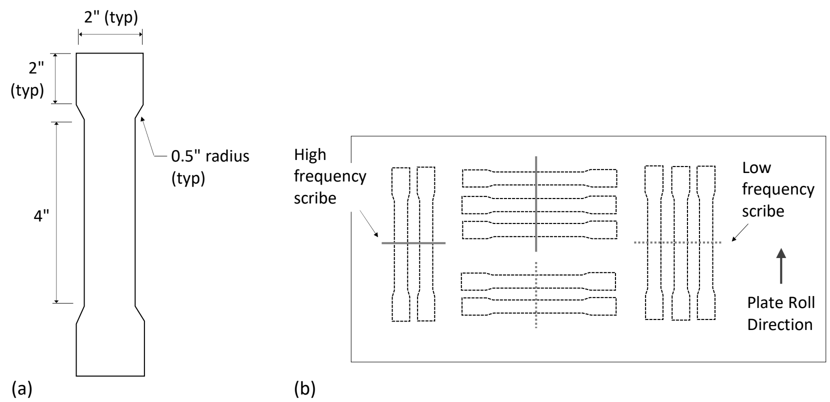


Figure 2. (a) Steel coupon geometry and (b) coupon material orientations from rolled A709 plate

Table 1. Experimental test matrix

Specimen Number	Pin-dot Marking Frequency	Material Orientation	Applied Stress Range [ksi]	Loading Rate [Hz]	Number of Cycles	Failure (X)/ Runout (O)
1	LF[a]	L[c]	35	20	1,697,702	X
2	LF	L	35	20	4,000,180	O
3	LF	T[d]	35	20	3,500,000	O
4	LF	T	45	20	1,639,460	O
5	LF	L	45	20	516,758	X
6	HF[b]	L	35	20	3,500,000	O
7	HF	L	45	20	626,000	X
8	HF	T	35	20	2,563,032	O
9	HF	T	45	20	3,086,352	O
10	HF	T	45	20	1,787,587	O

a. Low frequency marking speed (50 inches/min)
b. High frequency marking speed (10 inches/min)
c. Specimens fabricated in the longitudinal plate rolling direction
d. Specimens fabricated transverse to the plate rolling direction

3. Discussion of Fatigue Test Results

All specimens tested indicate a fatigue capacity above that expected for unmarked plates (fatigue detail category A). Specimens 1, was the only observed fatigue failure at the 35ksi stress range, which occurred at 1,697,702 cycles. Fatigue failure of specimens 5 and 7 occurred after 516,758, and 626,000 cycles respectively, when loaded at the 45ksi stress range. Other tested marked steel specimens resulted in runouts with applied cycles ranging from between 1,639,000 cycles and 4,000,180 cycles. Figure 3 plots the fatigue failure and runout test results along with the AASHTO A and B detail category S-N curves. In Figure 3, all fatigue test results appear above the detail category A S-N curve, indicating higher fatigue capacity. Marking frequency did not appear to have any effect on fatigue capacity, but it is interesting to note that all fatigue failures occurred in specimens oriented parallel with the plate rolling direction.

Table 2 compares the capacity ratios of the tested marked specimens with expected values from the AASHTO fatigue detail categories. From Table 2, the average fatigue capacity (considering measured runout values as the specimen fatigue capacity) from the tested specimens containing piece markings was 5.4 times greater than that expected from an unmarked steel plate (detail category A) subjected to uniaxial fatigue loading. The marked steel specimens had measured fatigue capacities of 11.3 times those expected from a B fatigue detail, on average. Note in Table 2 that the smallest ratio between measured and expected capacity was 1.88 for detail category A and 3.92 for detail category B.

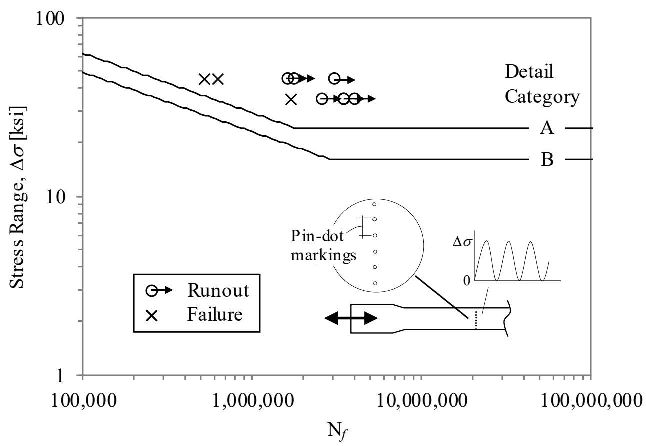


Figure 3. Comparison of test results with fatigue detail category S-N curves

Table 2. Measured excess capacity relative to fatigue detail category A and B capacity

Specimen Number	Applied Stress Range [ksi]	Number of Cycles, N	Failure (X)/ Runout (O)	N / N_A *	N / N_B **
1	35	1,697,702	X	2.91	6.06
2	35	4,000,180	O	6.86	14.3
3	35	3,500,000	O	6.00	12.5
4	45	1,639,460	O	5.98	12.5
5	45	516,758	X	1.88	3.92
6	35	3,500,000	O	6.00	12.5
7	45	626,000	X	2.28	4.75
8	35	2,563,032	O	4.40	9.16
9	45	3,086,352	O	11.25	23.4
10	45	1,787,587	O	6.52	13.6
			Average:	5.41	11.3

* Ratio of applied cycles and cycle capacity for fatigue detail category A
** Ratio of applied cycles and cycle capacity for fatigue detail category B

4. Conclusions on Pin-Dot Marking Fatigue Effects

In this study, the effects of the Telesis TMP3200/470 pin-dot marking system on the fatigue capacity of A709-Gr50 steel plate were investigated by fatigue testing a total of 10 marked coupon specimens. These specimens represented 2 marking frequencies (speeds of 50in./min and 10in./min), 2 applied stress ranges (35ksi and 45ksi), and 2 material orientations (both longitudinal and transverse plate rolling directions). Results from the 10 fatigue tests indicate that the surface markings from the Telesis TMP3200/470 automated marking system have no effect on the fatigue capacity of A709-Gr50 plate. All marked specimens tested achieved higher fatigue capacities than would be expected for unmarked specimens meeting the AASHTO fatigue detail category A designation.

5. References

[1] AREMA (2016). "Chapter 15: Steel Structures." *American Railway Engineering and Maintenance-of-Way Association (AREMA)* Volume 2

[2] AASHTO (2012). "AASHTO LRFD bridge design specifications (6th edition)." *American Association of State Highway and Transportation Officials*, Washington, DC.

[3] Frank, K., Smaras, V., and Helwig, T. (2012). "The effect of piec marking on fatigue performance of bridge steel." *Engineering Journal (AISC),* 2nd Quarter(2012), pp. 79-86.

[4] Manuel, M., and George, E. (2014). "Experimental investigation of the effect of surface markings on the mechanical integrity of weathering bridge steels." *Final Report to the Florida Department of Transportation,* Talahassee, FL, 32399

[5] ASTM (2016). "Standard Test Methods and Definitions for Mechanical Testing of Steel Products." A370-16, West Conshohicken, Pa.