The Effect of Piece Marking on Fatigue Performance of Bridge Steel

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ABSTRACT

An experimental study was undertaken to determine if markings used to identify fabricated steel using modern automatic impact stenciling equipment could be used on structures subjected to fatigue loading. The fatigue specimens with both numeric and alphabetic markings were tested. The results showed that the fatigue life of marked steel exceeded the fatigue design strength for Category A, the highest fatigue design category. Marking pieces with this equipment will not affect the fatigue design strength of the member.

Keywords: marking, fatigue, stamps, bridges.

INTRODUCTION

Steel components are marked during fabrication to help track the pieces through the fabrication process and ultimately to provide the erector with a method of identifying the correct location of the piece in the structure. Splice plates and the mating members are marked to ensure the correct orientation and location of the matched drilled pieces. A matched mark web member in a truss and gusset plate is shown Figure 1.

Typically, the marking has been performed manually using die stamps. The die stamps specified are often called out as low-stress stamps. The low stress refers to low increase in stress caused by the stamp. Die stamps labeled as low stress are available in the marketplace, but it is often not clear which specification these stamps satisfy. MIL-STD-792F(SH), *The Department of Defense Manufacturing Process Standard Identification Marking Requirements for Special Purpose* (Department of Defense, 2006), spells out the some of geometric requirements for low-stress stamps, shown in Table 1. The indentation is specified to be a round bottom with the minimum radius given in the table as opposed to the sharp “V” found on normal stamps. The specification also limits the depth of the stamp to a shallow 0.010 in.

Other marking techniques are available: the stamping can be done with a powder-actuated gun, inkjet stenciling, scribing, plasma torch, or impact stylus system. It is desirable to have a marking system that can be integrated into the numerical controlled cutting equipment currently in use in the steel fabricating industry. The pieces can be marked as they are cut, eliminating the possibility of mismarking pieces that look identical but may have slight differences in geometry. The marking should ideally be visible after application of paint and provide a permanent mark. In addition, the marking should not reduce the tensile and fatigue strength of the component.

A research study was conducted to determine the effect of marking using a computer-controlled impact stylus system. The system has been used in a semi-automatic mode to mark components for building and other nonbridge structures. It is a fast and flexible system that can be mounted and interfaced with existing equipment used for cutting the plates. The object of the research was to determine if steel marked with this system would have a reduced fatigue life or tensile strength.

The equipment used to perform the marking is manufactured by Couth of Spain. An electromechanical model MC2000 was used to mark the specimens. A picture of the equipment is shown in Figure 2. A typical mark made by the equipment is shown in Figure 3. The Gulim font used was used with a character height of 14 mm (0.55 in.). The stylus force was 150 lb. Note the larger and deeper indentations at the intersections formed at start and stop of the segments of the character.

SPECIMEN DESIGN, FABRICATION AND TESTING PROCEDURE

The fatigue specimens were designed to be tested in a closed-loop, 22-kip capacity, axial load testing frame. The test frame has hydraulically actuated grips that limited the thickness of the specimens. The width of the specimen was selected to provide a wide enough surface to accommodate

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Table 1. Low-Stress Stamp Geometric Requirements		
Character Size (in.)	Minimum Tip Radius (in.)	Nominal Impression Width for 0.010-in. Depth (in.)
1⁄16	0.005	0.020
3⁄32	0.006	0.021
1⁄8	0.007	0.022
3⁄16	0.008	0.026
1⁄4	0.010	0.031
3⁄8	0.014	0.042
1⁄2	0.020	0.062

the 7⁄16-in.-tall markings. The coupon-shaped specimen shown in Figure 4 was fabricated from 1⁄2-in. A709 Grade 50 plate. Two sets of specimens were made, one set with alphabetic and another with numeric marking. Two orientations of the characters were marked on each specimen. The marking was oriented 90 degrees from the opposite side to test both possible character orientations in one specimen. The specimens were flame cut and the edges ground smooth; the mill scale was left intact. The impact stylus used to mark the specimen is shown in Figure 5.

The chemistry and mechanical properties of the plate reported by the mill are given in Table 2.

The specimens were tested in the 22-kip closed axial test frame shown in Figure 6. The loading was tension to tension at a constant stress range of either 30 or 35 ksi. The minimum stress was 5 ksi for all specimens. The cyclic loading frequency was approximately 10 Hz. The tests were run continuously until either the specimen fractured or the test was deemed a runout.

After the fatigue tests were completed, two of the fatigue

Fig. 1. Example of stamped piece marking at a connection.

Table 2. Mill Test Results of Test Plate Material										
Element	C	Mn	P	S	Si	Cu	Ni	Cr	V	Nb
Percent	0.18	0.99	0.011	0.002	0.17	0.27	0.08	0.09	0.030	0.002
Yield Strength		59.8, 64.6 ksi			**Tensile Strength**			82.3, 80.6 ksi		

Table 3. Fatigue Test Results

Specimen Type	Stress Range (ksi)	Specimen	Number of Fatigue Cycles	Test Outcome	Ratio Test Cycles to Category A Design Life
Alphabetic	30	A1	2,700,241	Runout	1.7
	35	A2	2,672,452	Failed	4.6
		A3	6,000,028	Runout	10.3
		A4	7,513,600	Runout	12.9
		A5	9,241,204	Runout	15.8
Numeric	30	N1	2,674,040	Runout	1.7
	35	N2	3,181,753	Runout	5.5
		N3	6,009,136	Runout	10.3
		N4	5,079,358	Failed	8.7
		N5	6,826,604	Runout	11.7

specimens—one alphabetic and one numeric—that had not failed were loaded to failure in a larger test machine. As a control, an unmarked untested specimen without marking was also tensile tested.

FATIGUE TEST RESULTS

The initial two test specimens, one of each type of character, were tested at a stress range of 30 ksi. The testing was stopped after 2.7 million cycles. No cracking was found on the specimens. It was decided to test the next specimens at a 35-ksi stress range. The maximum stress of 40 ksi at 35-ksi stress range required almost 22 kips of force, the capacity of the test frame. The remaining specimens were tested at 35-ksi stress range. During the design of the specimens, it was assumed that they would fail before 1 million cycles, comparable to Category B of the fatigue specifications in AASHTO LRFD Bridge Specifications (2010). Only two specimens failed at the higher stress of 35 ksi. A summary of the test results is shown in Table 3.

Only two of the specimens failed, one of each type. The location of fatigue fractures are shown in Figures 7 and 8. The failures did not initiate at the deeper indentations that

Fig. 2. Marking tool and controller.

Fig. 3. Piece marking made with impact stylus system.

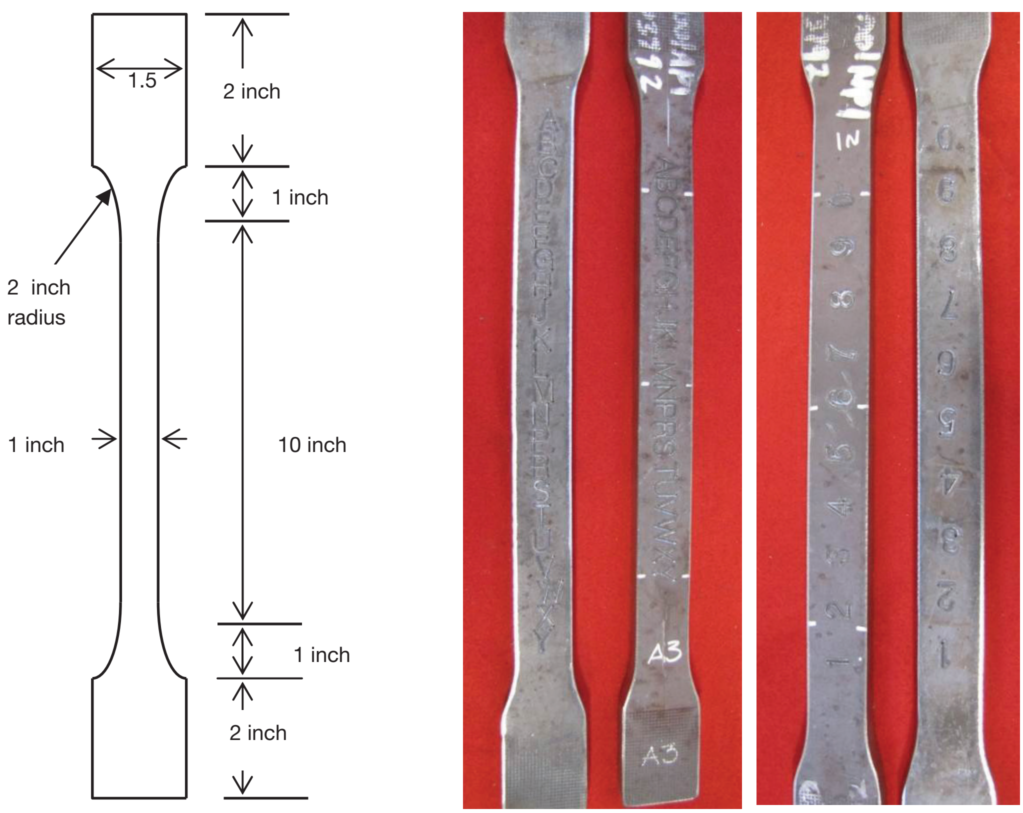

Fig. 4. Specimen configuration and marking.

occur at the intersections of character segments. The alphabetic specimen failure initiated at the letter "B" and the numeric at the numeral "1."

TENSION TEST RESULTS

The results of the tension tests done on the longest life fatigue specimens and an unmarked specimen are plotted in Figure 9. The plot shows the applied stress versus the cross head displacement. The yield and tensile strength of the marked specimen and fatigue tested specimens were similar to the unmarked control specimen.

DEPTH OF MARKINGS

The depths of the markings were measured using a thread micrometer. The pointed tip of the micrometer fit inside the indentation of the marking stylus. A minimum of three locations were measured on each character. The intersections of the character elements were included in the measurements because these appeared to have the greatest depth. A histogram of the measurements is shown in Figure 10. Two distinct peaks are evident; the first peak, at 0.010 in., is the depth away from the intersection. The second peak, at 0.017 in., is from the measurements at the intersections of character segments. The mean depth of all locations was 0.011 in. The maximum depth was 0.023 and the minimum was 0.004 in.

CONCLUSIONS

The marking of the specimens with electronically controlled impact stylus did not lower the fatigue strength specimens below the design strength for base metal in the AASHTO fatigue specifications. The design fatigue life of the marked material can be classified as Category A, the highest fatigue category. The markings, although slightly deeper than the military specification requirements, can safely be used on steel structures without concern for its effect on design fatigue performance. The tensile strength of the marked specimens was not reduced after subjecting the specimens to a 35-ksi stress range for more than 6 million cycles of loading.

REFERENCES

Department of Defense (2006), *Department of Defense Manufacturing Process Standard Identification Marking Requirements for Special Purpose Components*, MIL-STD-792F(SH), Washington, DC.

AASHTO (2010), *AASHTO LRFD Bridge Design Specifications*, 5th edition, AASHTO, Washington, DC.

Fig. 5. Stylus used to mark specimen.

Fig. 6. Specimen in test frame.

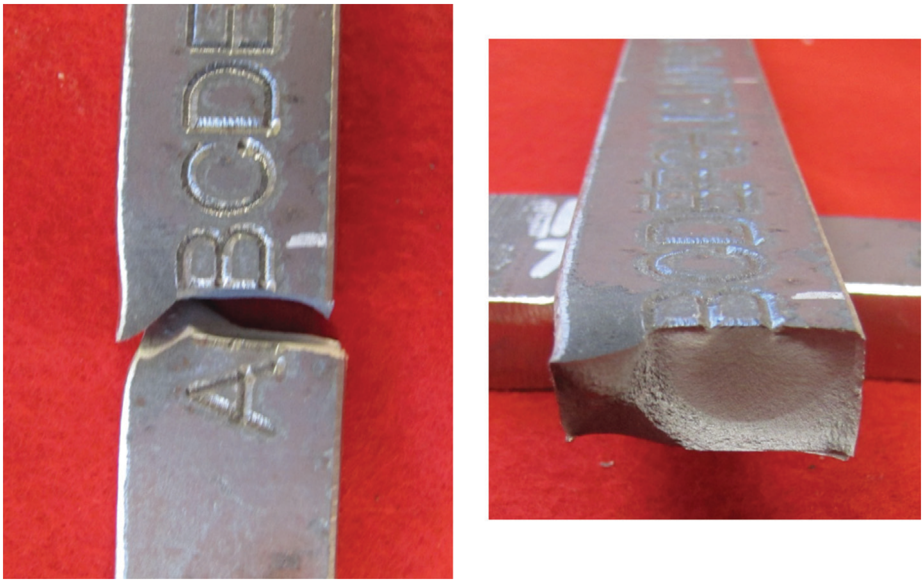

Fig. 7. Fatigue failure of alphabetic specimen.

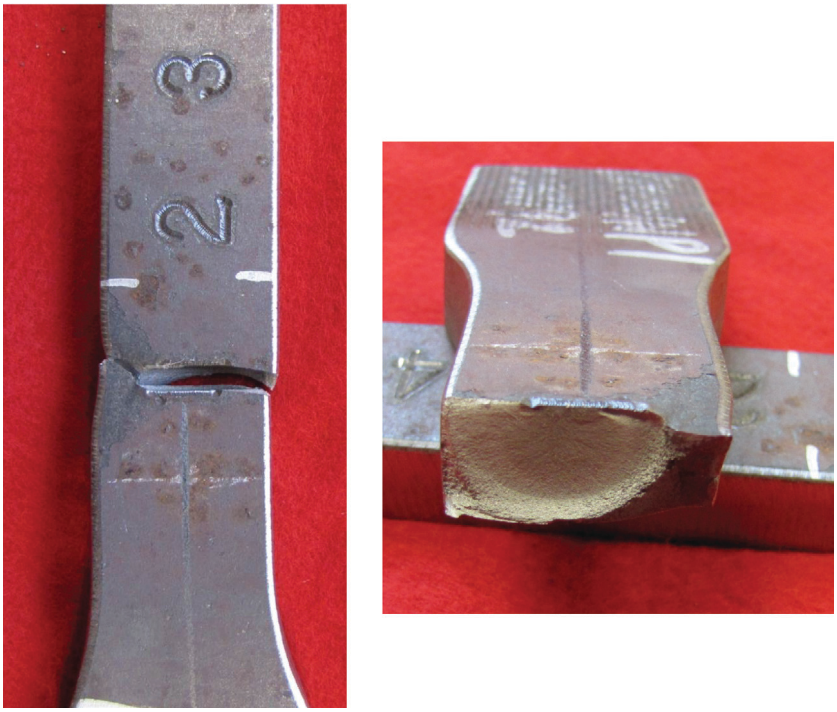

Fig. 8. Fatigue failure of numeric specimen.

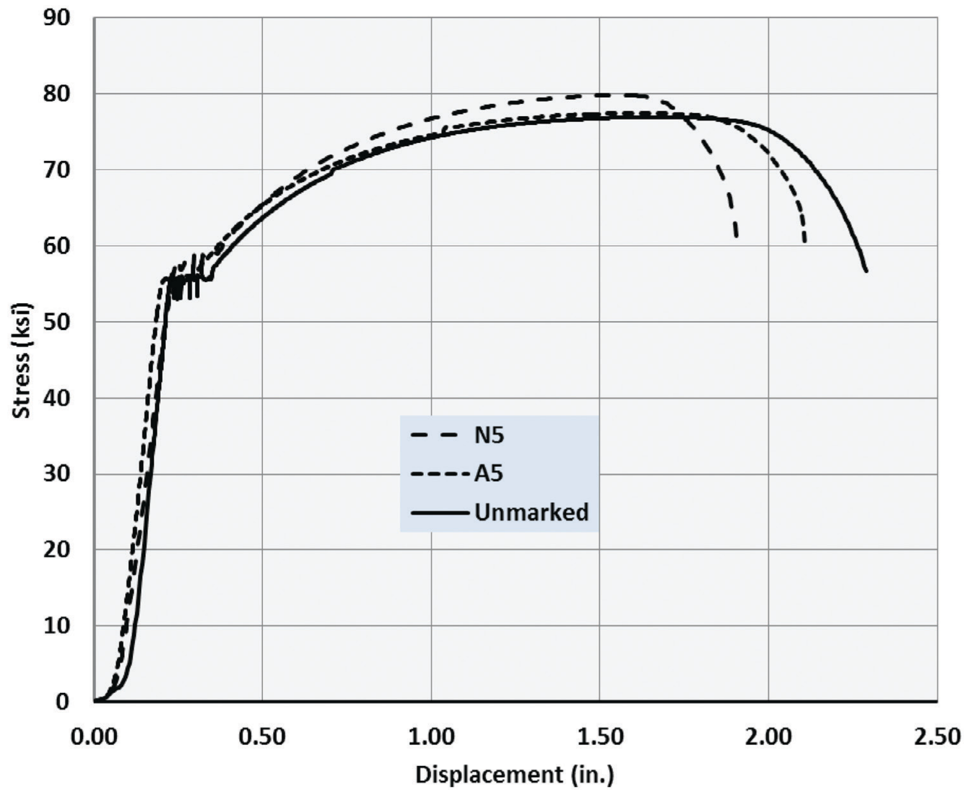

Fig. 9. Tensile test results.

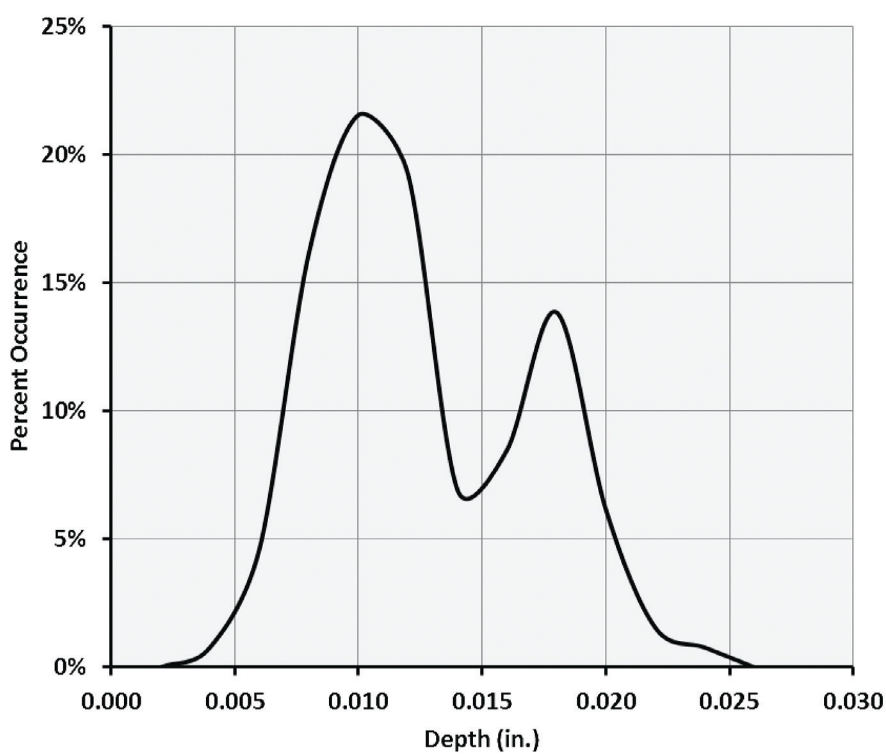

Fig. 10. Depth of stylus indentation.