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Automated pin-dot marking effects on steel bridge component fatigue capacity

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A B S T R A C T

During fabrication of multi-piece steel bridge assemblies, markings are often made on the steel surface to identify/track individual pieces or to provide reference for fabrication layout or later erection. Automated marking methods such as computer numerically controlled (CNC) pin-dot marking offer fabrication efficiencies; however, for marked steel sections subjected to frequent or repeated loading (i.e. bridge girders) many code specifications require experimental testing to verify any marking effects on fatigue capacity. In this study, the effects of automated pin-dot markings on the fatigue capacity of A709-Gr50 bridge steel are experimentally investigated from 13 specimens considering 2 marking frequencies (corresponding to marking speeds of 50 in./min and 10 in./min), 2 applied stress ranges (35 ksi and 45 ksi), and 2 material orientations (both longitudinal and transverse plate rolling directions). Results from the 13 high-cycle fatigue tests, along with other fatigue test results from the literature indicate that the surface markings from the automated marking systems have no effect on the fatigue capacity of the A709-Gr50 plate. All marked specimens achieved higher fatigue capacities than would be expected for unmarked specimens meeting the AASHTO fatigue detail category 'A' designation.

1. Introduction

During fabrication of multi-piece steel bridge assemblies, markings are often made on the steel surface to identify/track individual pieces or to provide reference for fabrication layout or later erection. While these markings can be made by various manual methods (crayons, tags, low-stress 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 components) surface indentations from these automated markings have the potential to affect the component fatigue capacity. To account for marking effects, specifications often require additional experimental verification to ensure adequate fatigue performance. For example, 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:

$$(\Delta F)_n = \left(\frac{120 \times 10^8}{N}\right)^{\frac{1}{3}} \geq 16\ \text{ksi} \tag{1}$$

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 Eq. (1).

Recent research efforts into the effects of automated piece-marking methods on plate fatigue capacities suggest little 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 for the limited number of samples tested, 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

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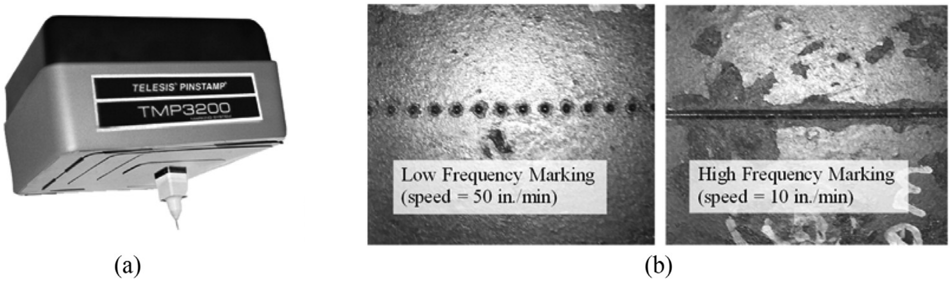

Fig. 1. (a) Telesis TMP3200/470 marking head and (b) marked steel surfaces.

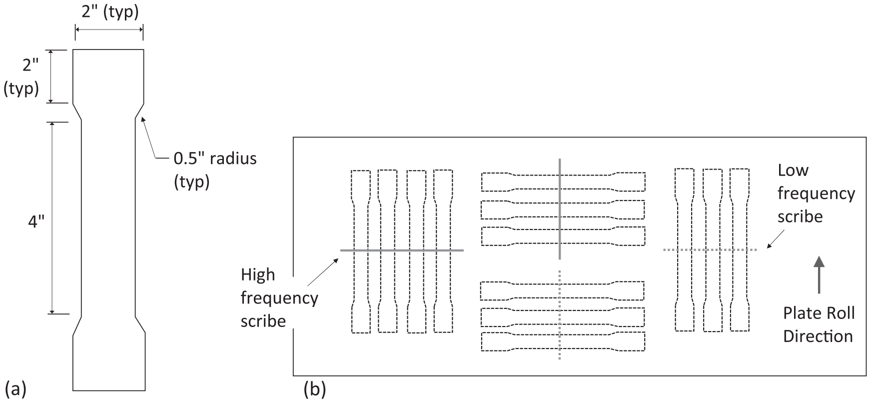

Fig. 2. (a) Steel coupon geometry and (b) coupon material orientations from rolled A709 plate.

implementation in fatigue prone applications covered by the AREMA guidelines.

This research study investigates the fatigue performance of A709-Gr50 steel (commonly used in steel bridge applications) marked using automated marking methods. To quantify the 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; however, existing experimental data from other automated marking systems is also considered for comparison. The study begins with a brief overview of the automated 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.

1.1. Automated marking system overview

Fig. 1(a) shows the marking head of the Telesis TMP3200/470 which was used for this study and Fig. 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 0.102 mm (0.004 in.) and 0.457 mm (0.018 in.). 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 Fig. 1(b)).

2. Specimen fabrication and testing methods

To investigate the effects of the automated pin-dot marking system on the fatigue capacity of A709-Gr50 steel plate, a total of 13 coupon specimens representing 2 marking frequencies (50 in./min and 10 in./min), 2 applied stress ranges (35 ksi and 45 ksi), and 2 material orientations (both longitudinal and transverse plate rolling directions) were fatigue tested. Fig. 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 in. A709-Gr50 steel plate prior to the cutting of each coupon geometry (see Fig. 2(b)). As shown in Fig. 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, to bound any marking effects. Table 1 presents the A709-Gr50 material properties, including the mill tested chemical composition.

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 20 Hz was used for each

Table 1
Mill test chemical composition and mechanical properties.

	C	Mn	P	S	Si	Cu	Ni	Cr	Mo	V	Al	Cb
Chemical composition [% by weight]	0.09	1.30	0.01	0.004	0.0015	0.019	0.01	0.03	0.006	0.05	0.028	0.033
Yield strength (σ_y) [ksi]			61.7									
Ultimate strength (σ_{ult}) [ksi]			71.6									
Elongation [%]			26									