Wear 310 (2014) 41–50

Contents lists available at ScienceDirect

Wear

journal homepage: www.elsevier.com/locate/wear

The effect of surface indentations on gouging in railguns

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ARTICLE INFO

Article history:
Received 17 September 2013
Received in revised form
10 December 2013
Accepted 14 December 2013
Available online 22 December 2013

Keywords:
Railgun
High-speed sliding
Hypervelocity gouging
Aluminum
Copper

ABSTRACT

Hypervelocity gouging occurs in high speed sliding systems such as rocket sled test tracks, light gas guns, and electromagnetic railguns. Gouging takes the form of teardrop-shaped craters on the rail surface, and occurs above a threshold speed which is dependent on the slider and rail materials. In this study, gouging of aluminum railgun armatures on flat and indented copper rails was performed to examine the effect of macroscopic surface defects on gouge onset velocity and morphology. Both galling and gouge craters were shown to initiate at existing macroscopic and microscopic defects. Macroscopically flat rail surfaces provide no practical advantage over indented surfaces insofar as gouge onset velocity is concerned. However, the shape of the resulting gouge craters can be significantly affected.

1. Introduction

Hypervelocity gouging is a damage mechanism that can occur in high-speed sliding contacts. Gouging was first reported for rocket sled test tracks by Graff and Dettloff in 1969 [1], and for electromagnetic railguns by Barber and Bauer in 1982 [2]. Gouge craters have a characteristic "teardrop" shape: beginning at a point and propagating outward, and ending in a raised parabolic crater lip as shown in Fig. 1. The formation of these craters is due to the simultaneous catastrophic plastic flow of both slider and rail materials. For rocket sled experiments the slider and rail materials were usually steel alloys [3]; whereas for railgun experiments the slider and rail materials were typically aluminum and copper alloys, respectively [4]. In both rocket sleds and railguns, gouging occurred above a threshold speed dependent on the slider and rail materials [5]. This threshold speed is a function of the hardness and acoustic properties of the slider and rail materials, with harder materials exhibiting a higher gouging threshold velocity [4]. Gouging can therefore be prevented by careful selection of slider and rail materials, though this becomes challenging at speeds above 2 km/s.

While the majority of observed gouges are generally tear-drop shaped, in some cases a slider will encounter a sufficiently large surface discontinuity, and the gouge will initiate across this defect. In this event the gouge will have a macroscopic starting width, as opposed to a small point which results in the characteristic teardrop crater. This occurs in cases where the slider runs over a joint between rail surfaces, as shown in Fig. 1b. For both railgun and rocket sled gouging there is anecdotal evidence that existing surface defects play a role in the onset of gouges, but it is unclear whether sufficiently large defects can cause gouges to develop at lower velocities compared to flat rails.

To address the role of macroscopic surface indentations on the onset of gouging in a controlled fashion, AA7075-T651 armatures were launched against C11000-H02 rails with macroscopic indentations in the rail surface. This was performed in two experiments: one experiment with large surface indentations in the rails, and one experiment without. Additional information on the experiments can be found in [6].

2. Experimental procedure

Railgun experiments were conducted at the University of Texas Institute for Advanced Technology Electromagnetic Launch Facility (IAT-ELF) [7]. The High-Energy Medium Caliber Launcher (HEMCL) was used to conduct the experiments, with 19 × 44.5 mm C11000-H02 copper rails surrounded by G10/FR4 fiberglass-epoxy insulators inside a laminated steel containment structure, a bore size of 38 × 76 mm, and a launch length of 4 m (Fig. 2). The resulting propulsive inductance gradient (L') of the rail configuration was approximately 0.54 μH/m.

Current measurements were made by numerically integrating dI/dt or "I-dot" signals from Rogowski coils on each capacitor

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http://dx.doi.org/10.1016/j.wear.2013.12.017

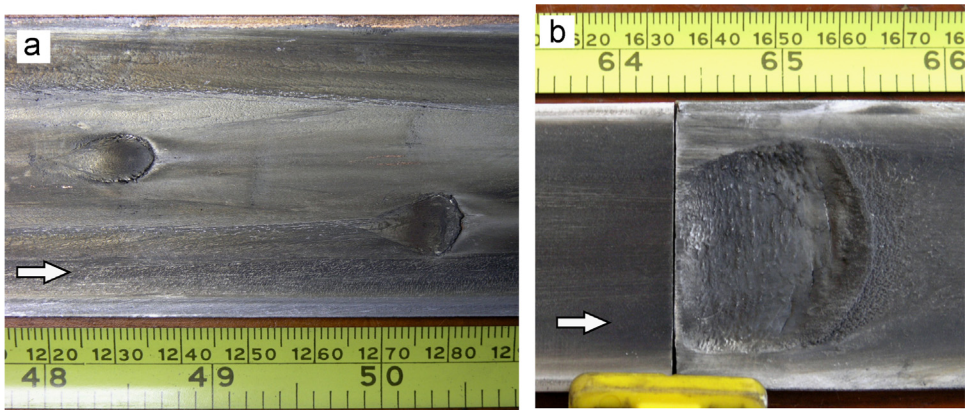

Fig. 1. Gouge initiation on (a) a flat rail surface, and (b) at a rail joint [6]. The tape measure units are mm (top) and inches (bottom) The direction of armature motion is indicated by the white arrows.

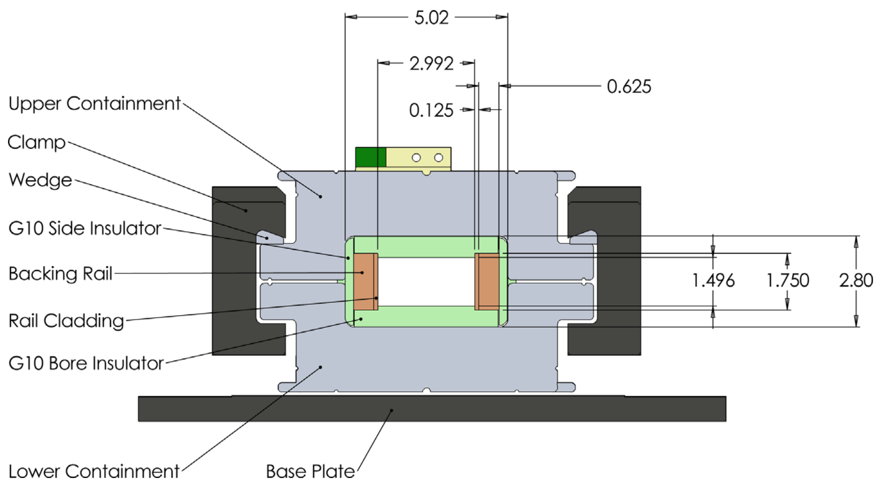

Fig. 2. Railgun launcher cross-section illustration (dimensions in inches).

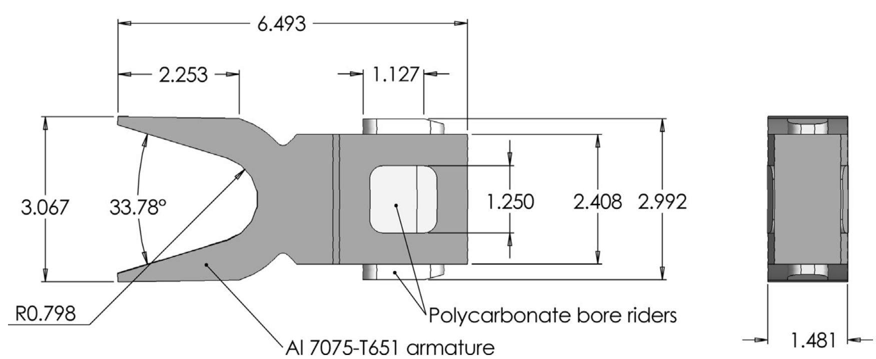

Fig. 3. HEMCL projectile dimensions (dimensions in inches).

bank's output bus [8]. The resulting current traces for all the banks were then summed together to calculate the total current flowing into the breech, and through the armature. Breech and muzzle voltage measurements were taken using current-viewing resistors wound around Pearson™ current transformers. B-dot (armature location) measurements were made using custom-fabricated circuit boards placed between the laminated containment sections down the length of the launcher [9]. 18 B-dot cards were used in the tests. All data were recorded with 12-bit LeCroy digitizers at a sample rate of 1 mega-sample per second (MS/s). The armature velocity profile was calculated by numerically integrating the acceleration versus time curve and performing a least-squares fit with the B-dot signals to determine the effective L' for each launch [10].

The acceleration of the projectile (a) is determined using Eq. (1), where m is the projectile mass, I is current, ρ_{air} is the density of air, A is the bore cross-sectional area, and v is velocity.

$$a = \frac{1}{m}\left(\frac{1}{2}L' I^2 - 1.2\rho_{air} A v^2\right) \tag{1}$$

The projectile used in the experiments is illustrated in Fig. 3. The design used a "C-shaped" armature made from AA7075-T651, which uses electromagnetic forces to keep the trailing arms in contact with the rails during the launch [11]. Polycarbonate bore riders were used to keep the launch package aligned in-bore and to keep the front of the aluminum body from contacting the rail and affecting the muzzle voltage signal.