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Failure Analysis of Electrical Pin Connectors

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Abstract

A study was initiated to determine the root cause of failure for circuit board electrical connection pins that failed during vibratory testing. The circuit board is part of an unmanned space probe, and the vibratory testing was performed to ensure component survival of launch loading conditions. The results of this study show that the pins failed as a result of fatigue loading.

Introduction

A failure investigation was initiated to determine the cause of circuit board failure that occurred during vibration qualification testing for the Mars Science Laboratory Entry Descent and Landing Instrumentation (MEDLI) project. MEDLI is an instrumentation suite installed within the heat shield of the Mars Science Laboratory (MSL) Entry Vehicle. The vehicle was designed to collect data about the Martian atmosphere, Thermal Protection System (TPS) performance, and aerodynamic characteristics of the MSL Entry Vehicle during entry and descent, to provide engineering design data for future Mars missions.

The Sensor Support Electronics (SSE) is mounted on the interior surface of the MSL heat shield. Vibratory testing was performed on these electronics to determine if they would survive the loads associated with their mission (e.g., launch, Martian atmospheric entry). During vibration testing of the SSE, anomalous data was observed. Post-test inspection of the SSE components revealed multiple failures of electrical connecting pins on the circuit board. These electrical pins are constructed from a material commercially known as Kovar¹, an alloy primarily composed of iron, nickel, and cobalt, having a coefficient of thermal expansion similar to glass, which is well suited for joining metallic and glass components. The failed pins were removed from the circuit board and examined using scanning electron microscopy. A photograph of the circuit board is shown in Figure 1a, and the processing chip with the failed connector pins is indicated. The processing chip is nominally square with 64 pins per side (256 total pins), and the pins are numbered as indicated in Figure 1a. Approximately 20-30 of these pins failed during vibratory testing. A higher-magnification of typical pin failures is shown in Figure 1b. This paper will present the findings of the microscopic failure surface inspection and discuss observations used to determine the root cause of failure.

Microscopic Examination

A total of five failed connector pins were analyzed that were selected for analysis due to slight macroscopic differences in the appearance of the pins (some were more severely deformed than others) and to analyze pins at different circuit board locations. The cross-section of these pins was nearly square with sides approximately 100 μm long. The pins consisted of Kovar cores that were coated twice, first with pure nickel, followed by an outer layer of gold. These pins were examined at high magnification in a scanning electron microscope (SEM), and chemical composition of selected failure surface features were determined using Energy-Dispersive X-ray spectroscopy (EDX).

¹ Kovar, an iron-nickel-cobalt alloy commonly used in electronic applications, is a trademark of Carpenter Technology Corporation.

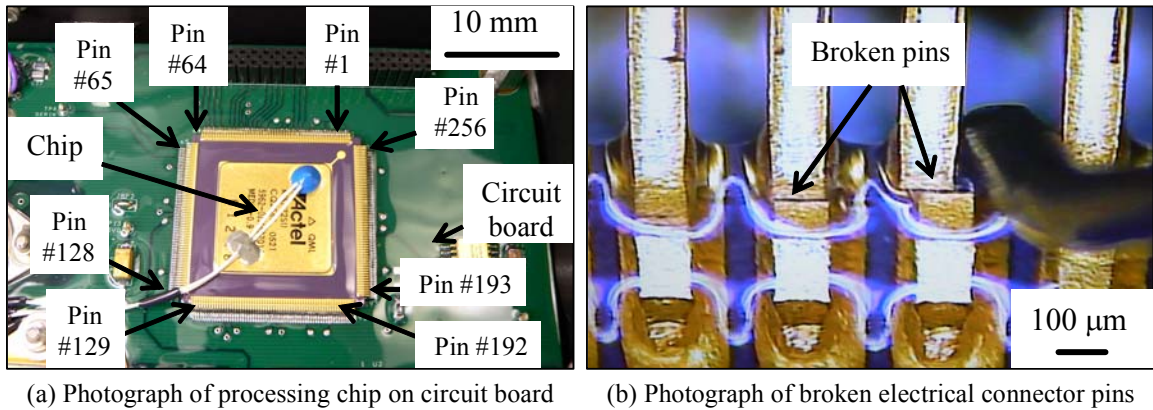


Figure 1. Photographs of failed electrical connector pins.

Findings

SEM examination revealed that all failure surfaces had very similar microstructural features despite any macroscopic differences observed. A typical SEM image of a pin failure surface (in this case, corresponding to Pin #130) is shown as Figure 2. Here, the pin is shown at an angle of approximately 45° to the failure surface to allow the sides of the pin, and the solder used to connect the pins, to be seen. The lack of obvious ductility (such as, reduction in area at failure) suggests that failure was due to a brittle mechanism such as fatigue crack growth. Detailed examinations of five pin failure surfaces (Pins #63, #64, #129, #130, and #131) have been conducted and results are presented in the following sections.

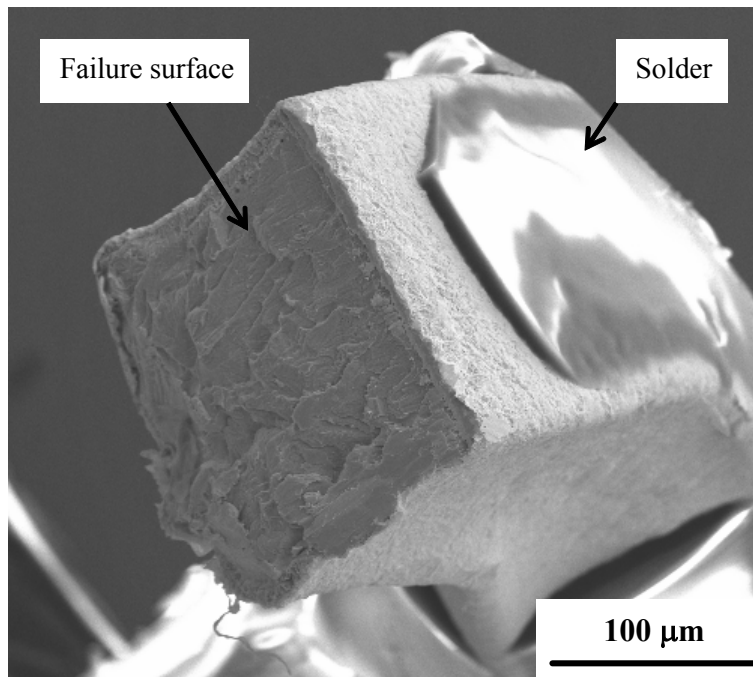


Figure 2. SEM micrograph of typical electrical pin failure surface (Pin #130).

Pin #63

SEM images of the failure surface for Pin #63 are shown in Figure 3. The entire failure surface is shown at relatively low magnification in Figure 3a, along with locations (b, c, d) of regions examined at higher magnification and supplied in Figures 3b, 3c, and 3d, respectively. Fatigue striations are observed in Figures 3b and 3c and are compelling evidence that crack propagation was driven by fatigue loading. By tracing these fatigue striations, which are indications of the crack front location at a given moment in time, back to a starter location, the apparent crack initiation location can be determined. For the failure surface of Pin #63, the apparent crack initiation location is shown in Figure 3d. Here, the apparent crack initiation site appears to have a smooth and faceted morphology relative to the surrounding crack surface.

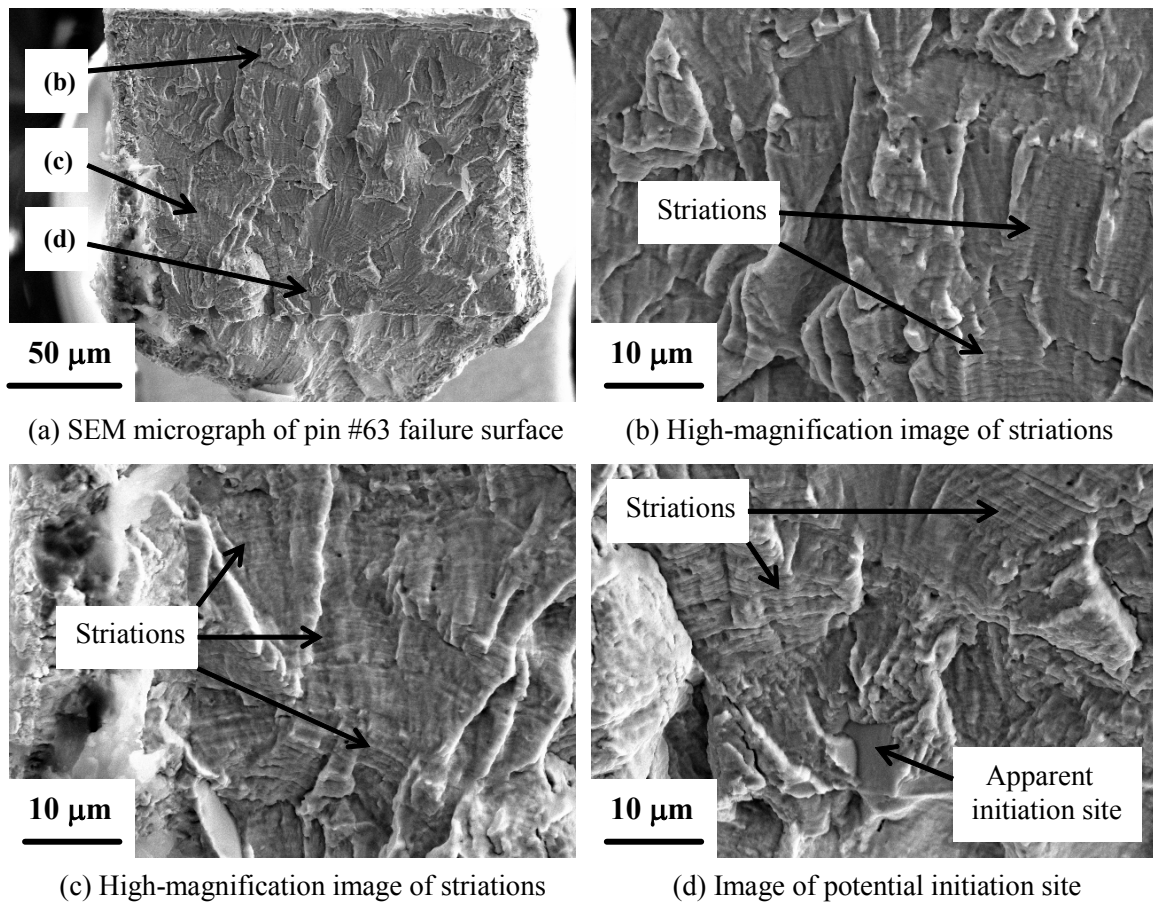


Figure 3. SEM images of the failure surface for Pin #63.

Pin #64

SEM images of the failure surface for Pin #64 are shown in Figure 4. The entire failure surface is shown at relatively low magnification in Figure 4a. Locations shown at higher magnification in Figures 4b and 4c are indicated (shown in Figure 4a as locations (b) and (c), respectively). Fatigue striations are observed in Figures 4b and 4c and are compelling evidence that crack propagation was driven by fatigue loading. An interesting feature observed in Figure 4c (indicated as location (d)) is shown at higher magnification in Figure 4d. This feature appears to be a particle, but the crack surface features do not suggest that this is a crack initiation site. No obvious crack initiation site was found on this crack surface.

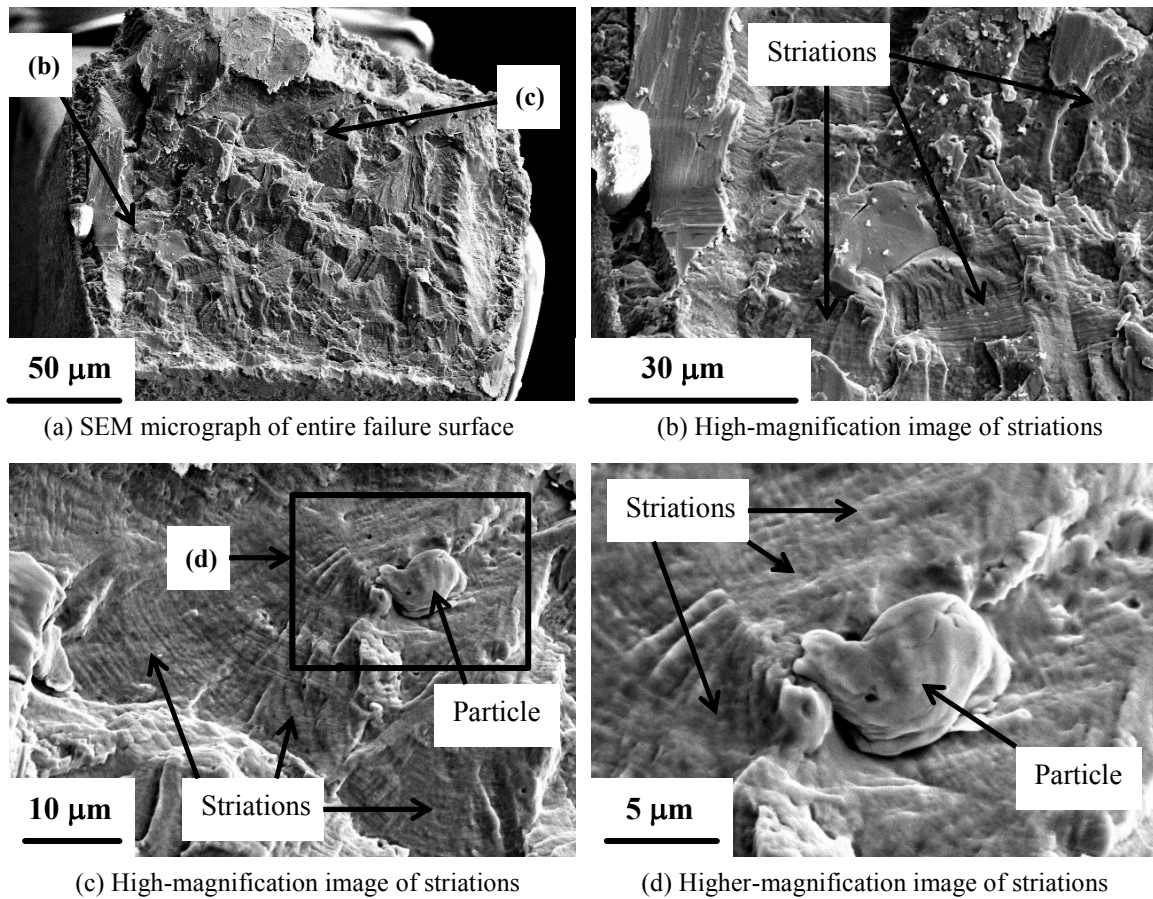


Figure 4. SEM images of the failure surface for Pin #64.

Pin #129

SEM images of the failure surface for Pin #129 are shown in Figure 5. The entire failure surface is shown at relatively low magnification in Figure 5a. Locations indicated in Figure 5a as (b), (c), and (d) are shown at higher magnification in Figures 5b, 5c, and 5d, respectively. Fatigue striations are observed in Figures 5b and 5c and are compelling evidence that crack propagation was driven by fatigue loading. These crack surface features can be used to determine the apparent crack initiation region, which is shown in Figure 5d. Similar to the findings for Pin #63, the apparent crack initiation site appears to have a smooth and faceted morphology relative to the surrounding crack surface.

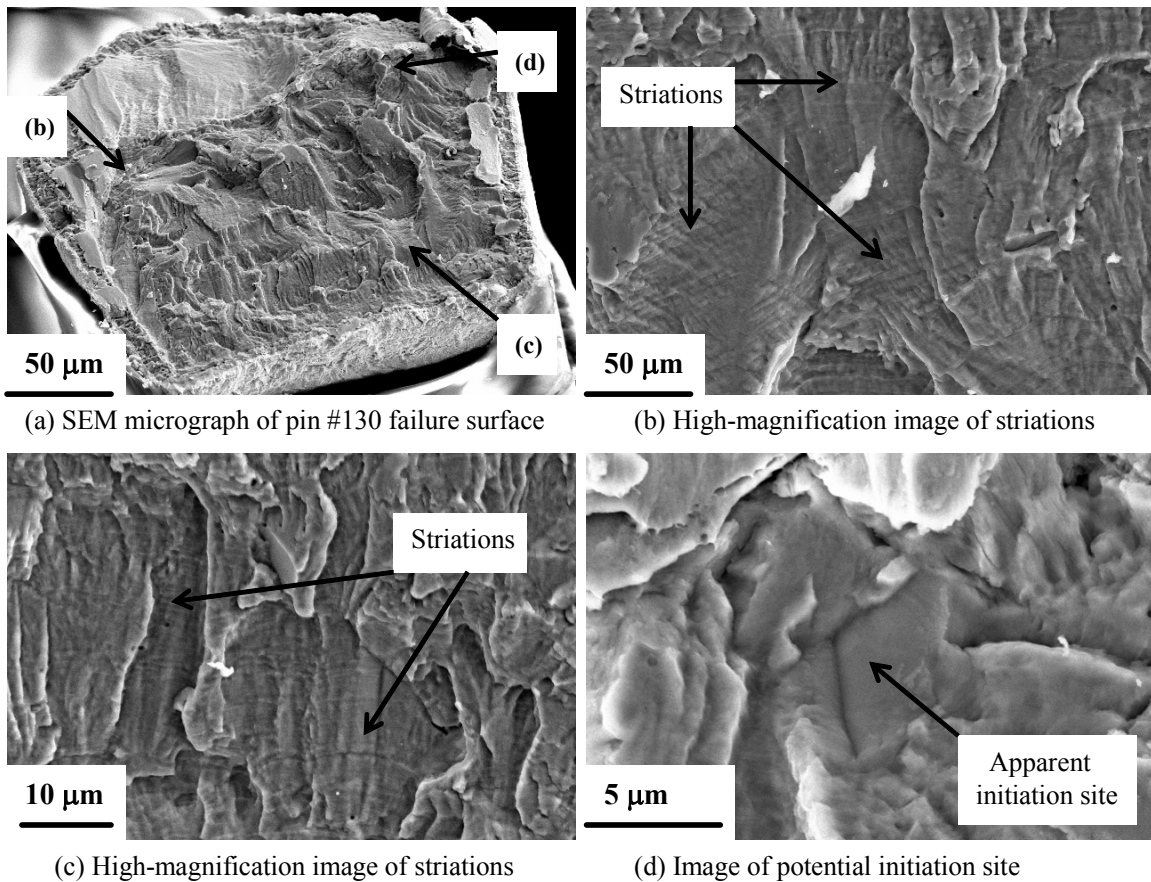


Figure 5. SEM images of the failure surface for Pin #129.

Pin #130

SEM images of the failure surface for Pin #130 are shown in Figure 6. The entire failure surface is shown at relatively low magnification in Figure 6a. Locations indicated in Figure 6a as (b), (c), and (d) are shown at higher magnification in Figures 6b, 6c, and 6d, respectively. Fatigue striations are observed in Figures 6b and 6c and are compelling evidence that crack propagation was driven by fatigue loading. These crack surface features can be used to determine the apparent crack initiation region, which is shown in Figure 6d. Similar to the findings for Pins #63 and #129, the apparent crack initiation site appears to have a smooth and faceted morphology relative to the surrounding crack surface.

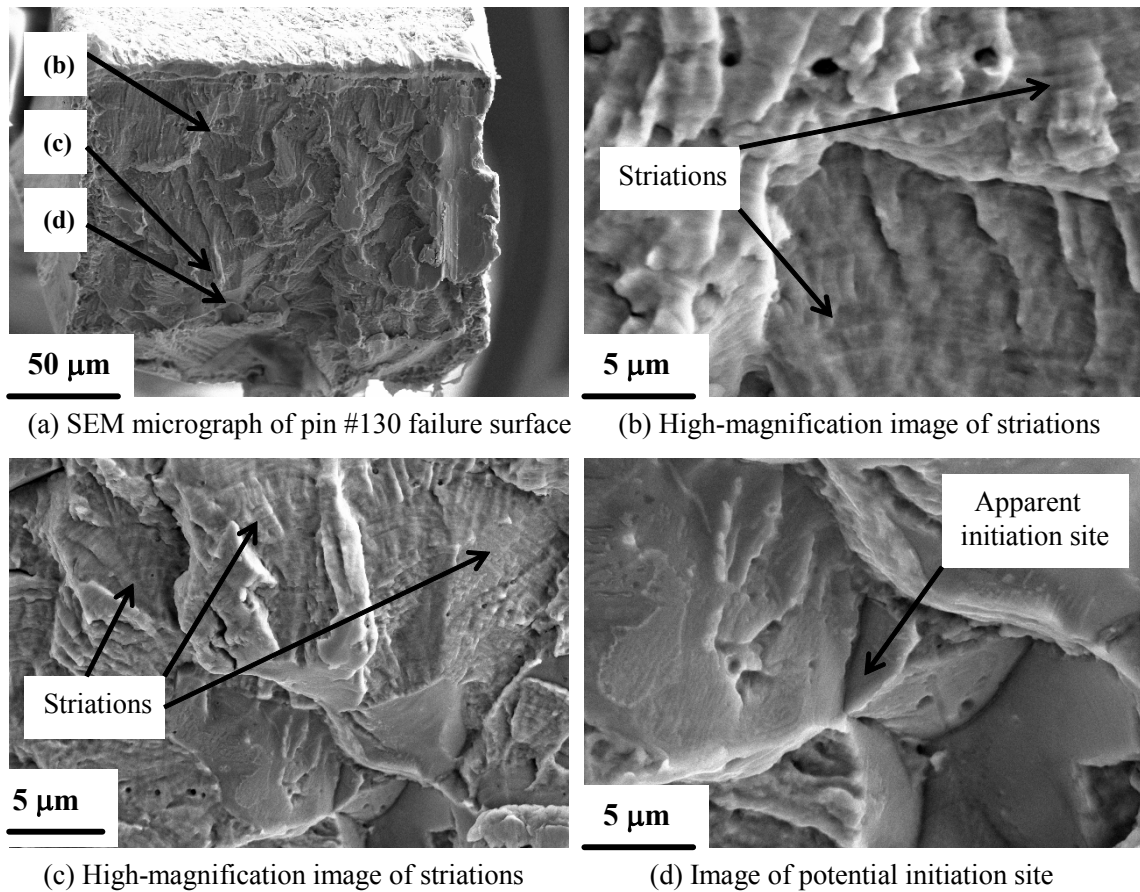


Figure 6. SEM images of the failure surface for Pin #130.

Pin #131

SEM images of the failure surface for Pin #131 are shown in Figure 7. The entire failure surface is shown at relatively low magnification in Figure 7a. Locations indicated in Figure 7a as (b), (c), and (d) are shown at higher magnification in Figures 7b, 7c, and 7d, respectively. Fatigue striations are observed in Figures 7b and 7c and are compelling evidence that crack propagation was driven by fatigue loading. These crack surface features can be used to determine the crack initiation region, which is shown in Figure 7d. Similar to the findings for Pins #63, #129, and #130, the apparent crack initiation site appears to have a smooth and faceted morphology relative to the surrounding crack surface.

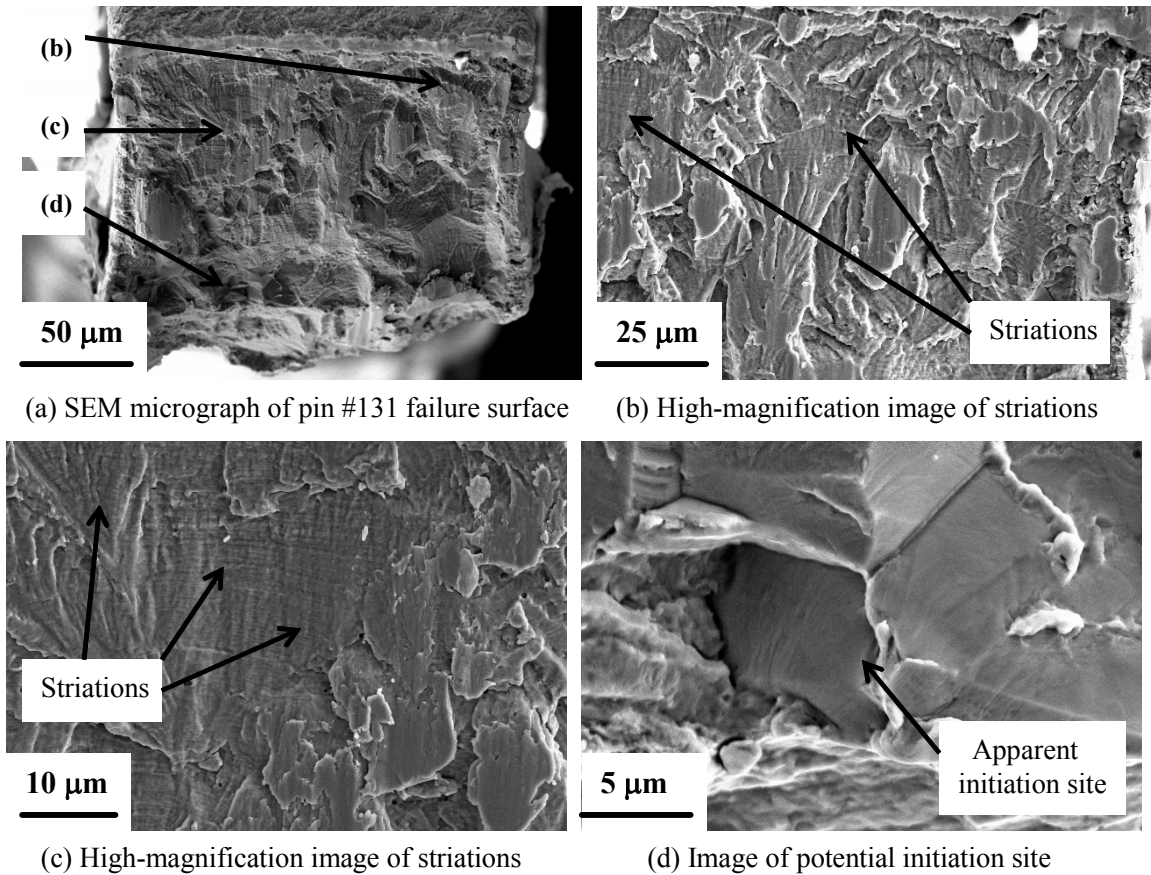


Figure 7. SEM images of the failure surface for Pin #131.

Chemical Analysis of Crack Initiation Sites

The difference in crack surface morphology of the apparent crack initiation sites, compared with the surrounding crack surfaces, suggested that a different damage mechanism may have occurred in these regions. The crack initiation sites identified for Pins #63 and #130 were chemically analyzed using Energy Dispersive X-ray (EDX). The results of this chemical analysis are presented in Table 1, along with the nominal composition of Kovar for comparison (ref. 1). Of the main alloying element of Kovar (iron, nickel, and cobalt), these crack initiation sites had very low nickel content relative to the nominal composition of Kovar. The nominal composition of Kovar presented in Table 1 is for the gamma (γ) phase of this alloy, an FCC condition that is widely used in the electronics industry (ref. 1). However, an

undesirable nickel-poor alpha (α) phase can occur, especially as the temperature of this alloy approaches 500°C. The reduction in nickel content is typical of that expected for a gamma-to-alpha phase transformation in Kovar (ref. 2). It is possible the temperatures reached during the soldering process may have triggered an unintended alpha-phase transformation. Based on the crack surface analysis, the presence of this alpha-phase serves as crack initiation sites thereby decreasing the fatigue resistance of the Kovar electrical pin connectors.

Table 1. Chemical composition of crack initiation sites compared with nominal values for Kovar.

Element	Kovar (weight %)	Crack initiation site Pin #63 (weight %)	Crack initiation site Pin #130 (weight %)
Iron, Fe	Balance (53.5)	65.55	63.02
Nickel, Ni	29.00	11.20	16.50
Cobalt, Co	17.00	20.54	19.77
Silicon, Si	0.20	-	-
Manganese, Mn	0.30	-	0.51
Aluminum, Al	-	1.98	0.19
Copper, Cu	-	0.73	-

Summary

Microscopic features found on the failure surfaces of electrical pin connectors revealed that the failure was the result of fatigue crack propagation. Crack front markers, such as striations, indicated that crack initiation occurred at features that appeared to be smooth and faceted (typically an indication of brittle failure). A chemical analysis revealed that these features associated with crack initiation had very low nickel content in comparison to the surrounding matrix. Although not proven, and outside the scope of this investigation, it is possible that these nickel-poor regions are an unintended second phase that may have formed as a result of component processing such as soldering the electrical connectors (heat).

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- (1) V.A. Fedorovich, V.A. Makarov, T.G. Korotkova, A.I. Rad'kov, and K.V. Trush, "Structural Transformations of FCC-phases in "Kovar" Alloy During Heating," Translated from *Metallovedenie i Termicheskaya Obrabotka Metallov*, No. 3, pp. 54-55, March, 1981.
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