NASA
Engineering Directorate
Materials Science Division
Kennedy Space Center, Florida

October 2, 2009

KSC-MSL-2009-0297

SUBJECT: Failure Analysis of Main Flame Deflector Nelson Studs

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1. ABSTRACT

NASA Structures engineers submitted two Nelson refractory studs from the main flame deflector at Launch Complex (LC) 39 A for analysis when they were observed to be missing a significant amount of material after launch. The damaged stud and an unused comparative stud were analyzed by macroscopic and microscopic examination along with metallographic evaluation of the microstructure. The stud lost material due to a combination of erosion and corrosion. Plain carbon steel readily forms an oxide layer in the coastal launch environment at Kennedy Space Center. The blast during a launch removes this brittle oxide layer, which then forms again post-launch, thereby further removing material. No indications of melting were observed.

2. FOREWORD

NASA Structures engineers submitted two Nelson refractory studs from the flame deflector at LC-39 A for analysis when they were observed to be missing a significant amount of material after launch (Figure 1). An additional, unused, stud was submitted for comparison. The installation date of the stud was unknown, but was thought to be for several years due to the absence of repair history of the flame deflector in this area.

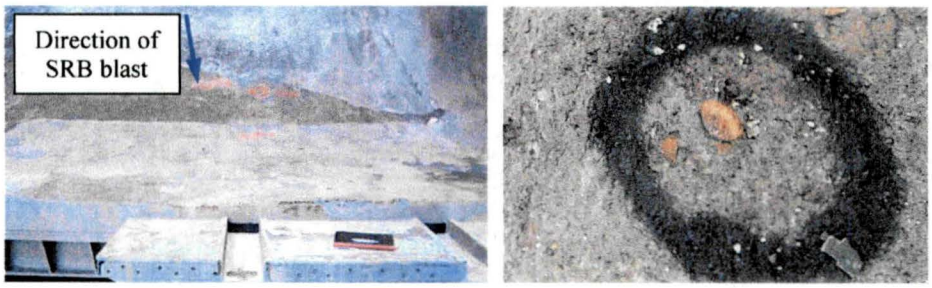

Figure 1. Customer supplied images of the location of damaged Nelson studs (orange paint) in the main flame deflector.

3. PROCEDURES AND RESULTS

3.1. The damaged and the unused flame deflector Nelson studs were photographed, as received (Figures 2 and 3). Both orange-red and black corrosion product were observed on the damaged studs, along with remnants of refractory material from the flame deflector and orange paint used to mark the studs. The studs were preferentially damaged on the side of the stud that was facing the solid rocket motor blast when they were installed (Figure 2, arrows).

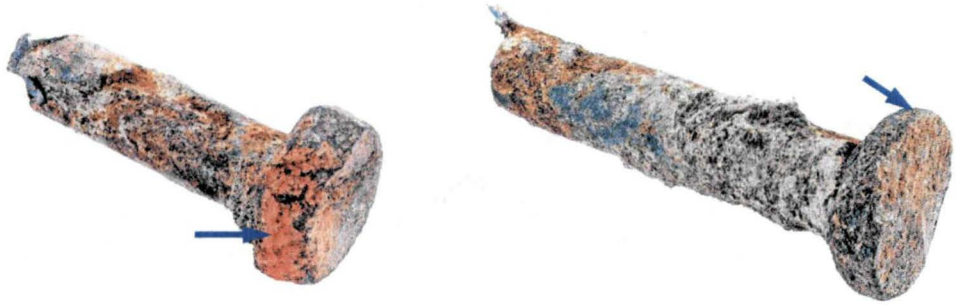

Figure 2. Flame deflector studs, as received. The arrows indicate the side of the stud that sustained the most damage, which correlated with the direction of solid rocket motor blast. Scale is two inches.

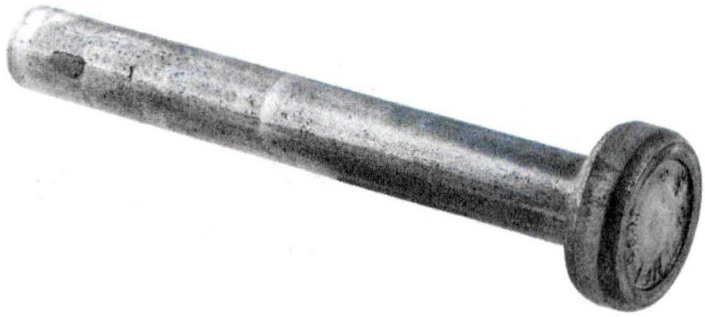

Figure 3. Unused Nelson stud, as received. Scale is two inches.

3.2. One of the studs was cleaned in an ultrasonic cleaner using Branson Oxide Remover (OR) to remove the corrosion product. Stereomicroscope observation of the cleaned stud revealed directional indications of erosion on the stud head that correlated with the blast direction (Figure 4, arrow).

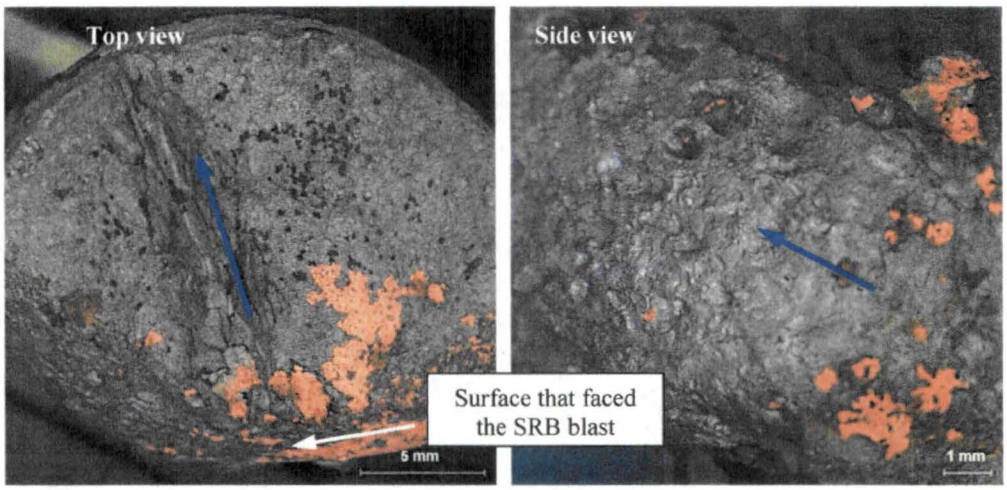

Figure 4. Stereomicroscope images of the top of the stud head (left) and the side (right) showing directional markings on the stud that correlated with the blast direction (arrows). Original magnifications: 6.3X (left), 12.5X (right)

3.3. SEM observation of the cleaned stud surface revealed a directional "horse-shoe" appearance to the eroded surface, which is typical for surfaces undergoing a combination of an erosive and corrosive process (Figure 5). Corrosion product (Figure 5, circled) remained adherent to the cleaned fracture surface.

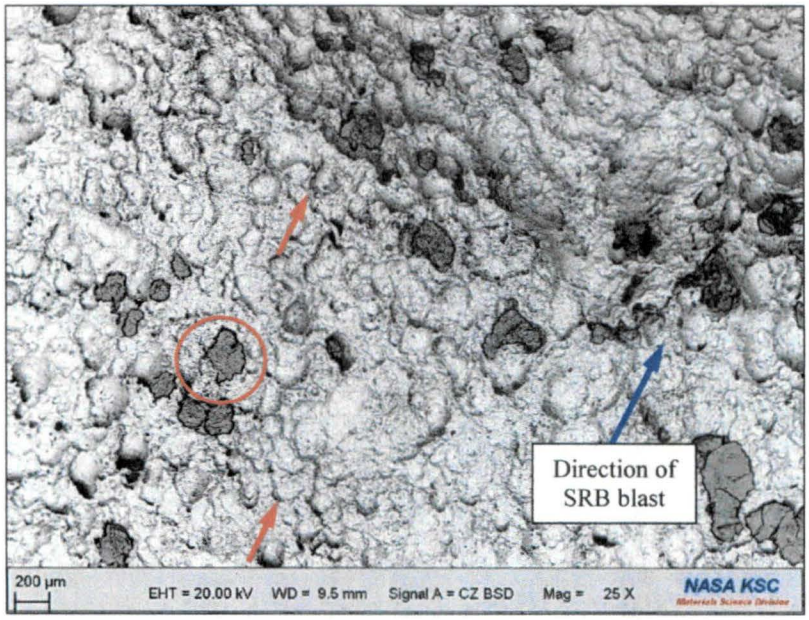

Figure 5. SEM image of the damaged surface showing a "horse-shoe" appearance to the eroded surface (red arrows). The circle indicates corrosion product that remained adherent to the fracture surface after cleaning. Original magnification: 25X

3.4. The unused stud was cross-sectioned, mounted, and prepared for metallographic examination. Flow lines were observed in the head of the stud, which is the typical macrostructure of a forged head (Figure 6, upper row). Cold worked grains were observed in the head of the stud, which is typical for forged microstructures (Figure 6, bottom left). The body of the stud consisted of predominantly ferrite grains with minor amounts of elongated pearlite (Figure 6, bottom right), which is typical for rolled plain carbon steel.

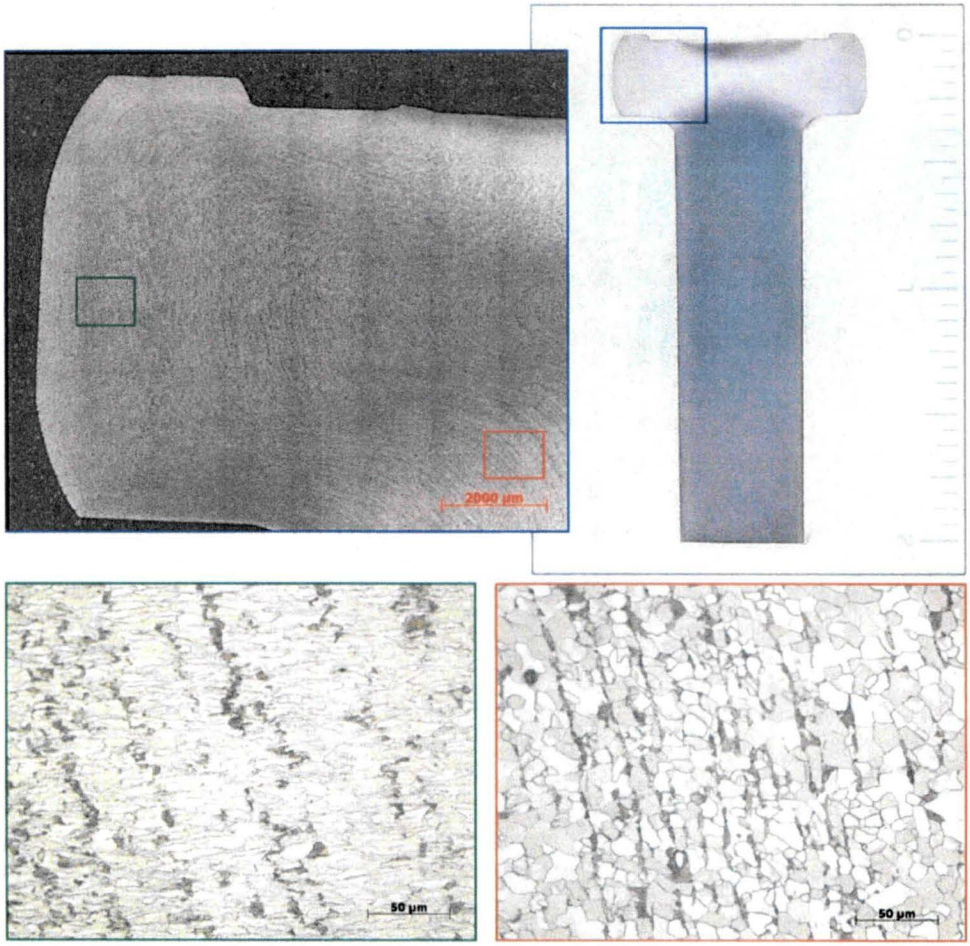

Figure 6. Micrographs of the unused stud cross section, showing the macrostructure (top row) and the microstructure (bottom row). The microstructure of the stud consisted of ferrite grains (light) with minor amounts of pearlite (dark). The head of the stud displayed cold worked grains (bottom left) as compared to the body of the stud (bottom right). Original magnifications: 1.5X (top right), 10X (top left), 300X (bottom row)

3.5. The damaged stud was cross-sectioned, mounted, and prepared for metallographic examination. Some of the oxide layer that was not removed during cleaning remained on the surface of the stud (Figure 7, arrows). The half

of the head that was not damaged still had a typical forged macro- and microstructure. The damaged side of the stud head consisted of pearlite with ferrite at the grain boundaries (Figure 7, bottom left). The base of the stud consisted of ferrite grains with minor amounts of pearlite (Figure 7, bottom right). The changed microstructure in the damaged area of the head is an indication of heating in the stud. No dendrites were observed, which would be an indication of melting and resolidification of the stud material.

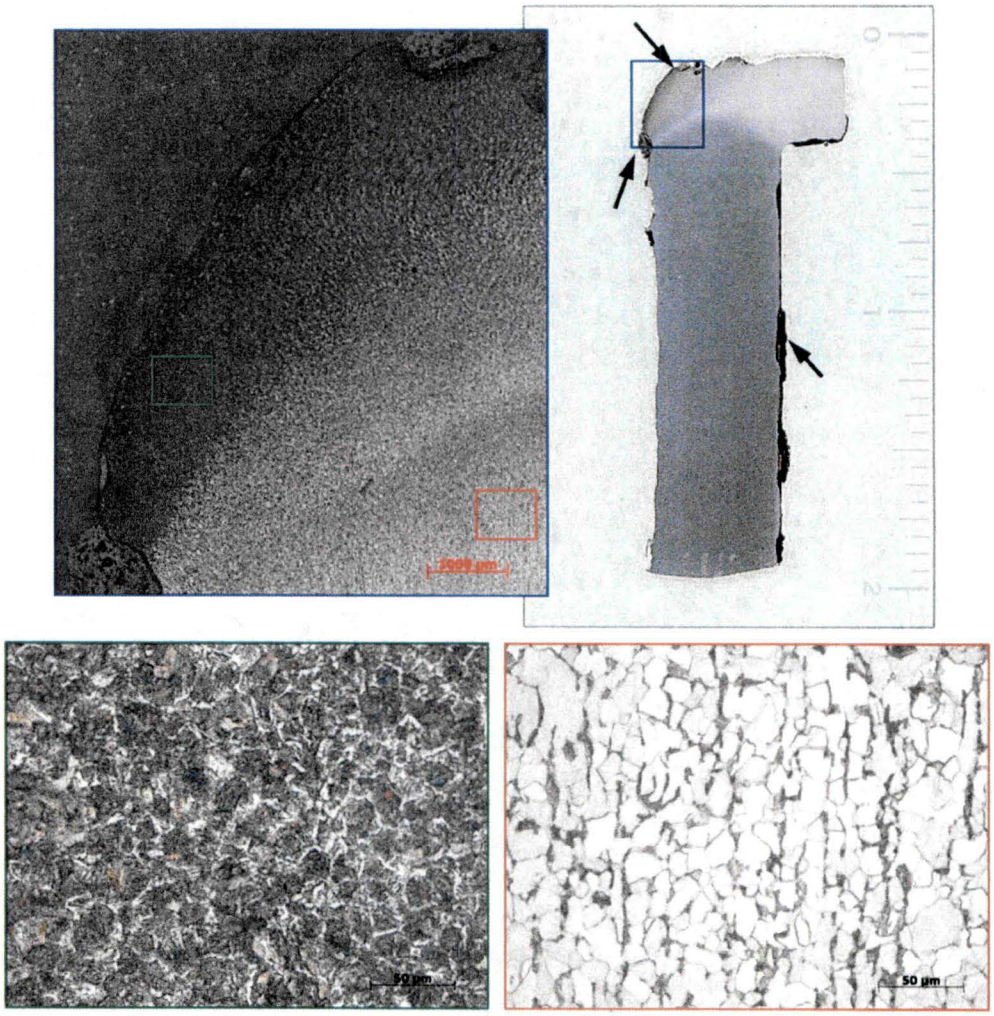

Figure 7. Micrographs of the used stud cross section, showing the macrostructure (top row) and the microstructure (bottom row). The microstructure in the damaged portion of the stud head (bottom left) consisted of pearlite (dark) with ferrite (light) at the grain boundaries. The microstructure of the body of the stud (bottom right) consisted of ferrite grains (light) with minor amounts of pearlite (dark). Original magnifications: 1.5X (top right), 10X (top left), 300X (bottom row)

3.6. The polished cross section was analyzed using energy dispersive spectroscopy (EDS) via the SEM. The studs were composed primarily of iron with trace amounts of manganese and carbon, which is consistent with plain carbon steel.

3.7. Microhardness measurements using a Vickers indenter and a 500 g load were taken on cross-sections of the damaged and unused studs (Figure 8). The microhardness of the shaft of the used stud averaged 185 Vickers scale (HV), which converts to a hardness of 90 Rockwell B scale (HRB), per ASTM E 140, *Standard Hardness Conversion Tables for Metals*. The microhardness of the shaft of the unused stud averaged 180 HV, which converts to a hardness of 89 HRB. These hardness values are typical for rolled plain carbon steel. The microhardness of the damaged area averaged 200 HV, which converts to 93 HRB. The microhardness of the undamaged stud in the head location averaged 250 HV, which converts to 22 Rockwell C scale (HRC). The reduced hardness of the used stud in the damaged area is due to the relieved cold work, indicative of heating in this area.

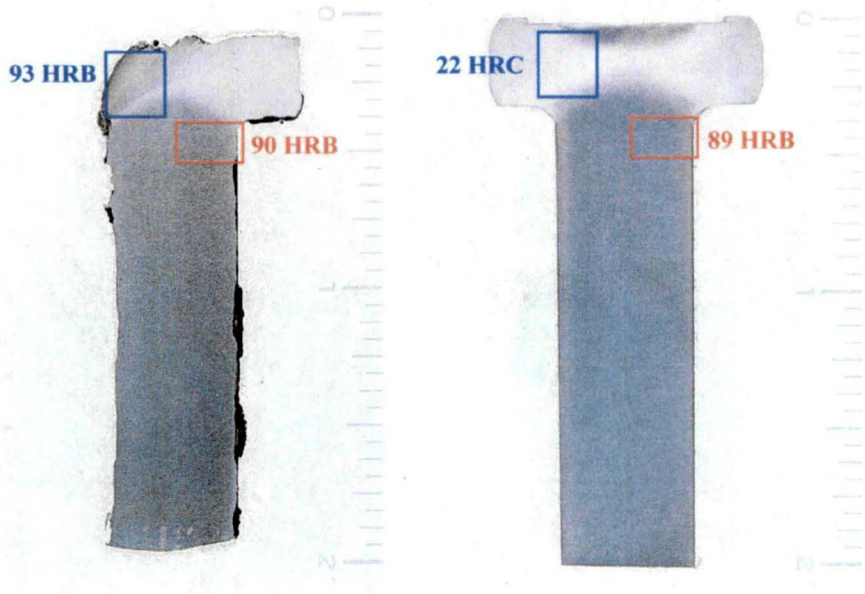

Figure 8. Images showing the locations of the microhardness measurements.

4. CONCLUSION

The stud lost material due to a combination of erosion and corrosion. Plain carbon steel readily forms an oxide layer in an outdoor, marine environment. The blast during a launch removes this brittle oxide layer, which then forms again post-launch, thereby further removing material. No indications of melting were observed.

EQUIPMENT: LEICA MZ95 stereoscope ECN 3059494/serial 4415571
Zeiss EVO 60 SEM S/N 0465 with Oxford INCA EDS S/N 13131
Zeiss Z1m Metallograph, S/N 3837000175
Struers Duramin Microhardness Tester, S/N 5640020

RELATED DOCUMENTATION: ASTM E 140, *Standard Hardness Conversion Tables for Metals*

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