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# Investigating and interpreting failure analysis of high strength nuts made from nickel-base superalloy

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ABSTRACT

The United States Air Force experienced failures of three separate zero-time, 220 ksi Inconel 718 nuts that were installed on A-10 aircraft. During the investigation, another nut fracture occurred on an operational jet. This bolt/nut combination had very few service hours on it and was well below the expected service life. A thorough review of the procurement data revealed that all the failed nuts had passed lot tests successfully. This led to concerns that the current procurement test requirements were insufficient to identify nuts that could unexpectedly fail in service. Another factor convoluting the situation was evidence of shanking on one of the four failed nuts. In order to determine the risk for potential future nut fractures, a novel experimental approach was developed and executed to evaluate the strength and integrity for all 220 ksi Inconel 718 nut manufacturers and sizes utilized on the A-10 aircraft. These experiments were designed to have a combination of shanking and pre-load and push the nuts to extreme limits with the intent of uncovering sub-par capability. The amount of torque at failure and the distance traveled by the nut were the two measures of performance. In addition to these experiments, a rigorous metallurgical evaluation was performed to determine if there were any metallurgical anomalies within the fractured and tested nuts. The measured torque values were then used to correlate to the metallurgical evaluations and the results are presented. This novel testing method provided quantitative data to determine the impact of the manufacturing process on the performance of the bolt/nut combination and demonstrated that a characterization of the microstructure alone may not provide evidence of corresponding nut performance.



## 1. Introduction

When installing a high strength bolt and nut combination, one of the specified geometric constraints is the final thread length of the bolt outside of the nut, often referred to as thread protrusion. This geometric constraint is adjusted by increasing or decreasing the grip length of the bolt and/or the number of washers used between the bolt head/nut and fastened material. Through this installation process it is possible to ensure that the nut is properly threaded on the fastener, ensuring the defined amount of clamp-up torque. If the proper installation process is not followed and too few washers are used (or none at all), it is possible to drive the nut past the threaded region of the fastener and up onto the straight shank of the bolt. This is known as shanking. When

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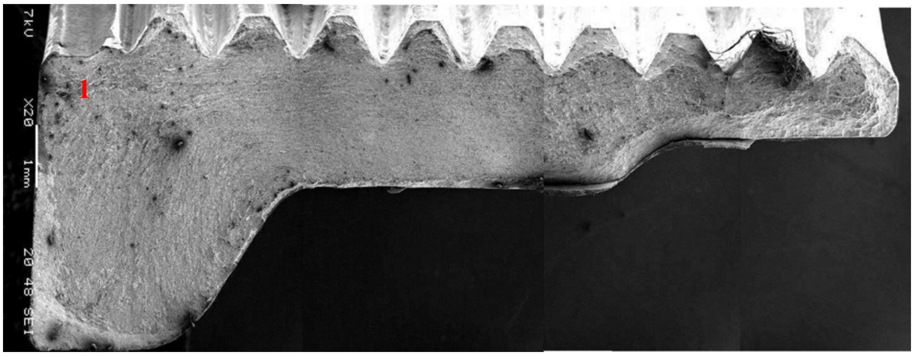


**Fig. 1.** Composite of SEM micrographs showing fracture surface topography for the failed EWA nut from [3].

the nut is driven up onto this larger diameter, there is a significant potential of rupturing due to the radial expansion. This failure does not require any external loads or forces to exceed the fracture strength of the material. The failure is caused by the strain/displacement induced as the nut is radially expanded around the larger fastener shank diameter. This failure can be instantaneous or be caused in a 'creep-like' manner, either at elevated or lower temperatures.

Fatigue and fracture of the bolt due to improper installation is one of the significant structural problems in fastener tension joints. Typically, bolts have a specified torque requirement to ensure proper joint preload. In fatigue critical joints it is essential that the proper amount of preload is reached during installation to eliminate joint gapping and improve the overall fatigue performance of all the components within the joint [1]. In the situation when the nut is shanked, the required joint preload is not achieved, thus making the joint susceptible to premature fatigue failure. More importantly, the stresses induced in the nut and the associated risk of premature nut fractures compromises the integrity of the joint.

In 2014, the A-10 experienced four 220 ksi Inconel 718 nut fractures. Three of the four nuts fractured post-installation but prior to the component ever being installed on an aircraft and exposed to service loads. One of these nuts exhibited evidence of shanking. The fourth nut fractured in the fleet after limited usage with no evidence of shanking. Nuts manufactured from Inconel 718 were commonly installed on the A-10′s new Enhanced Wing Assembly (EWA) and therefore, a clear understanding of the root cause of the failures was critical to support any fleet-wide inspections or part replacements.

During the initial assessments, it was unclear how much shanking had contributed to the failures, given that only two of the four failures exhibited any evidence. Another key factor in the evaluation was that all of the nuts had passed initial quality

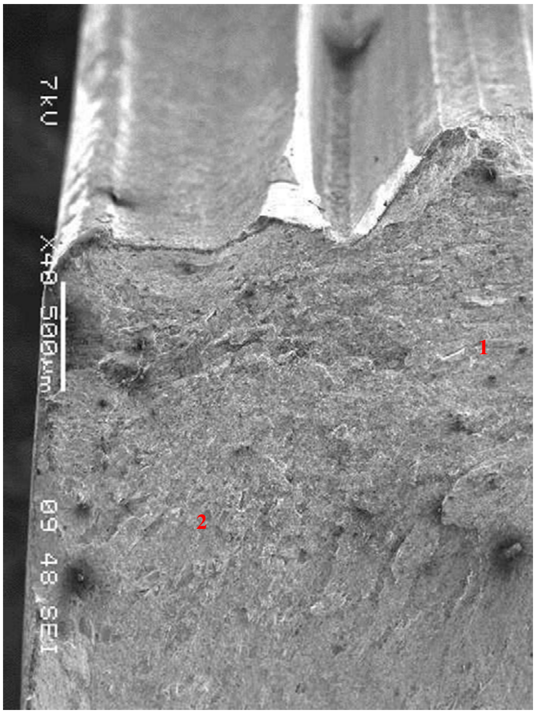


**Fig. 2.** SEM micrographs showing fracture surface topography in corner region Location 1 in Fig. 1 for the failed EWA nut from [3].