

Failure analysis of engine crankcast bolts treated by alodine anodic technology

Yanpeng Feng, Haijun Tang, Ping Shu

China Academy of Civil Aviation Science and Technology

Abstract—Crankcase is an important part of civil turbofan engine. In this case, some turbofan engine crankcase nuts were found failure during the manufacture process. Compared to new nuts, with Cd coating to avoid the electrochemical corrosion between different matels, the coating in failure nuts was mottled and dis-continuent, with scanning electron microphotography, the matrix was opposed and indentified. So some results was collected that, the aluminum alloy crankcase was process by alodine treatments for anti-corrosion, but the steel nuts were never move out during the treatments process. So the coating in nuts was erosion and drop from matrix. During the assembling process, the nuts were extrusion and failure.

Keywords—Alodine treatment; Aluminium alloy; steel; Hydrogen embrittlement; aircraft engine

I. INTRODUCTION

Cadmium electroplated high strength steel fasteners are widely used for assembling threaded joints as perfectly lubrication and excellent electrochemical corrosion resistance, between different alloys [1~3]. Alodine treatment is one kind of anodic technology of aluminum alloy. The major object of it is to format anodic oxidation film on the surface of workpiece. The thickness and abrasive resistance are two importance evaluation indexes. The oxidation film formed by alodine treatment is thinner, comparing with other anodic technology, but it can extremely maintain the surface accuracy and surface roughness of virgin workpiece. So, it is widely used in military industry and aviation industry.

When steels are protected by corrosion resistance coating of sacrificial metallic, it is increasing risk of hydrogen embrittlement for two reasons [4]. First, if the coating process is electrodeposition a small proportion of the plating current produces hydrogen, it will trapped into the coating and absorbed by the matrix steel slowly. This hydrogen may storage at grain boundary to decreasing the strength.

Second, hydrogen can also be absorbed during a sacrificial coating corrodes in service process, especially in humid environment. In this case, exposed portions of the steel substrate act as cathodic sites where hydrogen is generated by the reduction of water. If this hydrogen is absorbed in sufficient quantities it can also lead to failure of high strength steel and this process is termed hydrogen re-embrittlement [4].

In this case, one aviation engine crankcase was schedule check and maintenance, after several thousands cycles. During the manufacturing and maintenance process, the bolt and

crankcase were treatment by alodine 1200S solution for 3 minutes. Crankcase was fabricated out of 7075 aluminum alloy, and bolts were fabricated out of stainless steel with cadmium electroplated coating. During the assembling process, the bolts were failed about one third, by shearing-off of threads. The operated force on the bolts was lower than normal operating standard. So the object of this article is to clarify the reason of the failure and proposing solutions.

II. EXPERIMENTS

Observation of failure bolt revealed that the surface color of failure bolt and virgin one was obvious different. Color of failed bolt is shiny with bright metal color, while the virgin is grey brown color, and corrosion was absent in virgin one. On the head-end piece of the bolt, shearing-off of several threads was noticed, as shown in Fig.1.

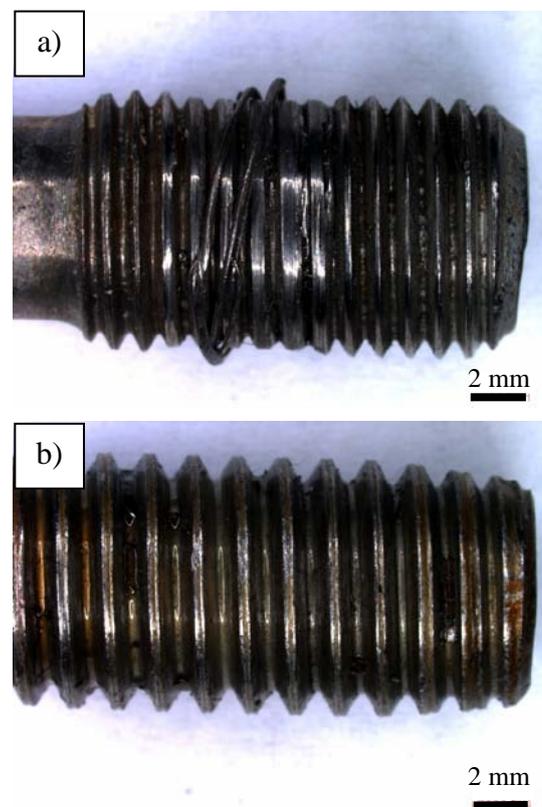


Fig. 1 Treads of bolts. a) Bolt treated by alodine 1200S, b) virgin bolt

Macro photograph of failed and virgin bolts are shown in fig.2, both bolts are used, and some abrasion marks and deposition could be found in thread root position of both bolts. Except of the different color in threads parts, the rod of the bolts is different too. As mentioned above, the failed bolts were process by alodine treatment with the engine crankcase, so the bolts were exposed in alodine solution, absolutely. From macro view, metallic luster is found in the screw thread surface and rod for untreated bolt, which is mottled and discrete for the treated bolt.

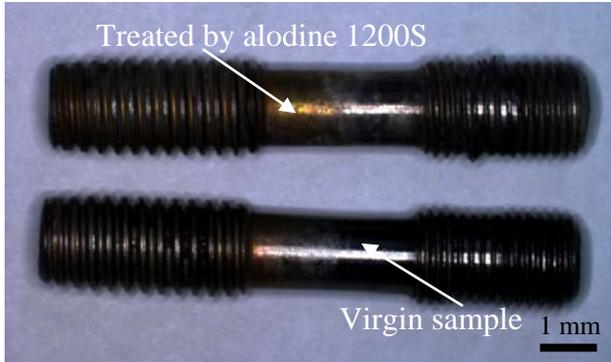


Fig. 2 Optical photograph of virgin bolt and treated by alodine 1200S solution

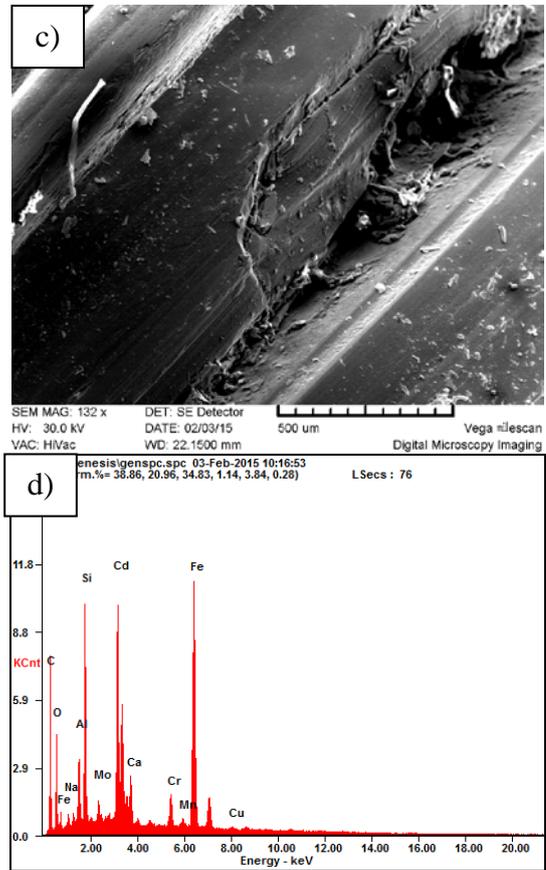
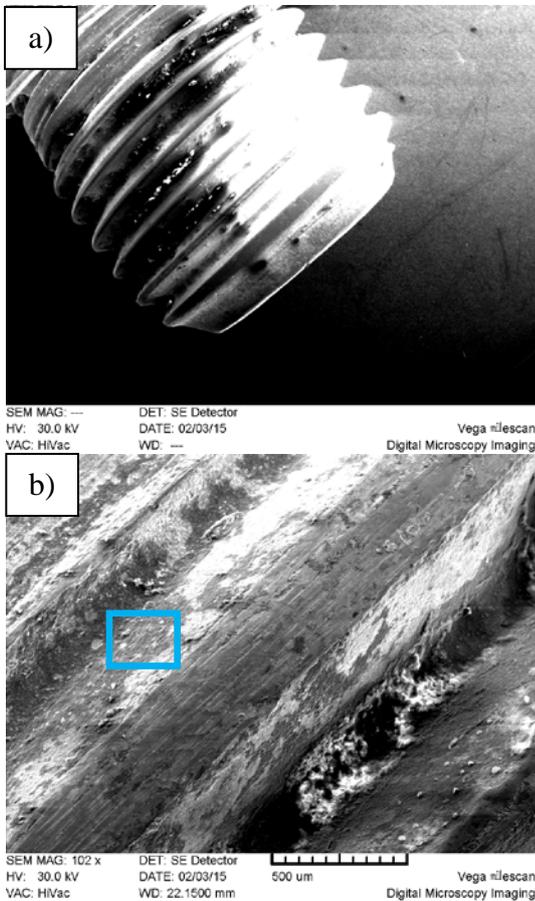


Fig. 3 Microstructure and energy dispersive spectrum (EDS) of failed bolt a) top of failed bolt; b) Surface of screw thread; c) root of screw thread; d) EDS of position in fig.3b.

Microstructure of treated bolt is shown in Fig.3. After the assembling process, many grinding products are formed and accumulated at root of threads, as shown in fig.3b. The energy dispersive spectrum (EDS) of the position in the profile of thread, where without any grinding marks, as the blue block in fig.3b is shown in fig.3d. The chemical elements including of Cd, Si, Fe, Mo and Cr are found. The element Cd may come from the coating materials, and Fe, Cr may come from matrix of bolt, and Mo, Si may come from lubricant materials. The shearing-off threads are shown in fig.3c, that were cut off during the assembling process after alodine treatment. But the dimensional matching between bolt and nut may no problem for it has been assembling once, and the force apply on bolt is control and monitor, and it's under the standard force. So the problem is that, why the bolt is so weaker?

The surface of untreated bolt (virgin bolt) is shown in fig. 4, it's uniform, continuous and smooth. The surface is covered with uniform particulate matter (coating materials), that proved lubrication as mentioned by other articles. So why, the microstructure of this kind is not cutting or shearing during the assembling process? And the coating materials could proved perfect protect for the bolts.

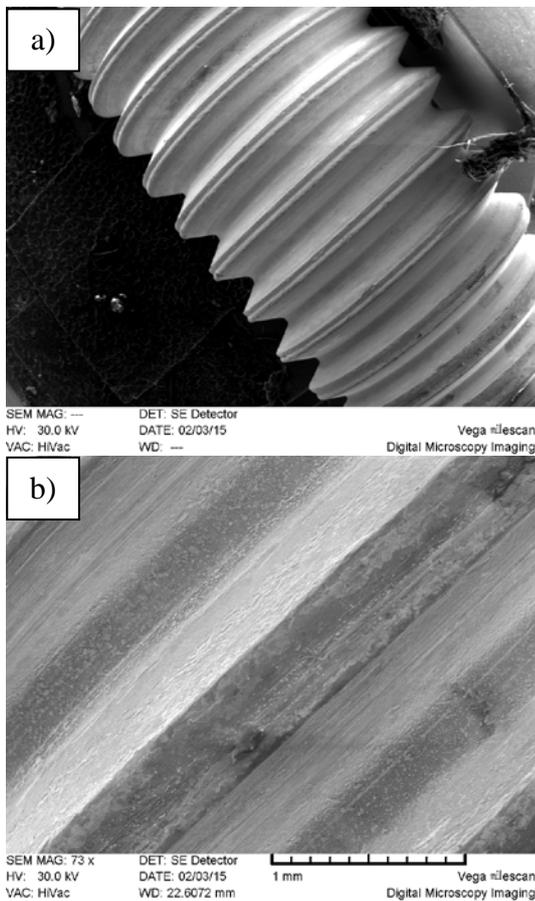


Fig. 4 Microstructure of untreated bolt a) thread of untreated bolt; b) surface of thread

To clarify the above problems, microstructures and EDS of untreated and treated bolts are investigated and shown in fig.5. Surface of untreated thread is covered smooth coating with distribution of parallel mark that may be profile of matrix formatted during machining process. Surface of treated bolt is covered porous and loose coating and machining mark of matrix is exposed. EDS result shows that the main chemical element of untreated bolt surface is Cd, which is coating materials. But the chemical elements of treated bolt surface are Cd and Fe, Cr, that are matrix materials.

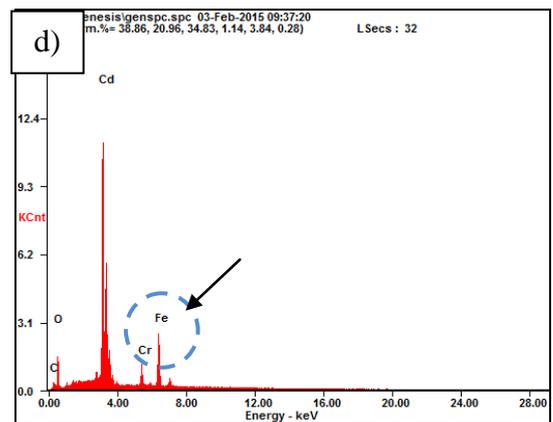
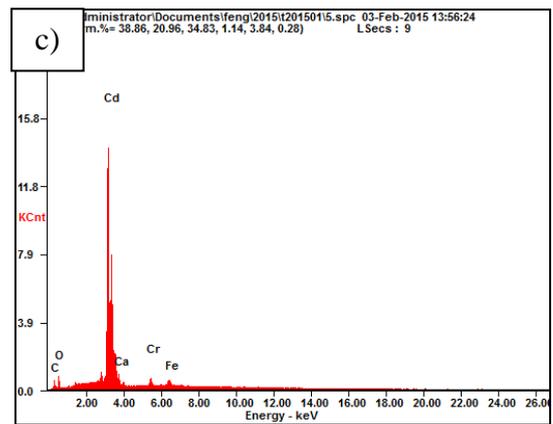
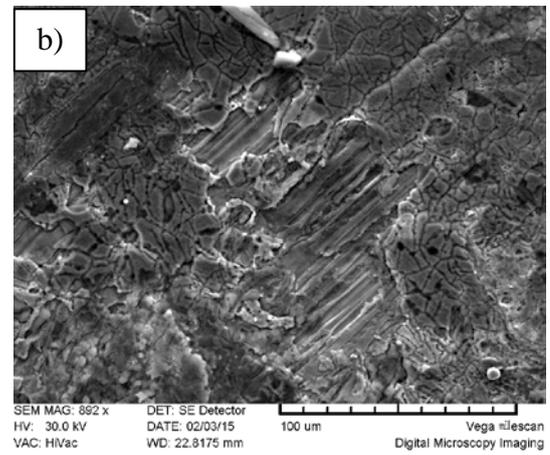
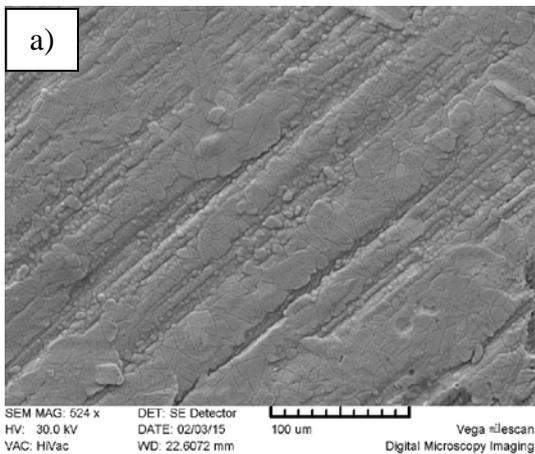


Fig. 5 Comparison of different microstructures and EDS between treated and untreated bolts a) surface of threads for untreated bolt, b) surface of threads for treated bolt, c) EDS of untreated threads, d) EDS of treated bolt.

III. DISCUSSION

Result of microstructures and EDS clarified that, the treated process corrode the Cd coating and lead to the loose and disconnected coating. During the assembling process, it cut off from surface of thread and accumulated in the root of thread. Deposition of deciduous coating materials may change the dimensional mater between bolt and but, and increasing the shearing force between bolt and nut.

But the discussion above may not cover all the reason of the failure process. The matrix of bolt is high strength stainless steel. The thread may not be cutting off so easy, lower than the force of the standard requirements. It's mentioned that, the Cd electrodeposition coating process by small proportion of the plating current produces hydrogen. During the alodine process the solution is chromic acid solution without plating current, the Cd electrodeposition is corroded as mentioned above, and then aluminum element of engine crankcase is more active than Fe element of bolt in the acid environment. Galvanic battery reaction may by the following process:



The anode electrochemical reaction formed on the surface of bolts and hydrogen is absorbed by matrix and storage in grainboundary. Which decreasing the strength of stainless stain and weaken the thread. So, during the assembling process after the alodine treatment, the cut off coating and matrix materials were accumulated in the root of thread. The original dimensional coordination was change. Cooperated with the hydrogen brittlement affect that decreasing the strength of thread. The failed process may include the both effects.

This hydrogen can lead to delayed failure of high strength steel under load and it is the usual practice to bake such components for up to 24 h at 200 °C to remove the hydrogen.

IV. CONCLUSIONS

1. During the alodine treatment, the origin Cd electrodeposition coating is corroded, chips and drop-off matrix metal accumulated in the root of thread that change the dimensional conditiation.
2. Hydrogen formed by the galvanic battery reaction during the treatment, absorbed by metal of bolts, Hydrogen brittlement decrease the strength of thread and induce the shearing-off of thread.

V. ACKNOWLEDGEMENTS

The research described in this paper was supported by Natural Science Foundation of China U1333124. The authors acknowledge the financial assistance of the civil aviation safety capacity building fund 152146903107.

References

- [1] K. Gangadhara Reddy, Abhay K. Jha, V. Diswakar. Failure of cadmium plated maraging steel tension bolt, *Engineering Failure Analysis* 8 (2001) 263-269
- [2] John S, Balasubramanian V. *Metal finishing*, 1984, 82(9) : 33
- [3] A.Aguero, J.C.Del Hoyo, J.Garcia De Blas, et al. Aliminum slurry coatings to replace cadium for aeronautic applications. *Surface and Coatings Technology* 2013 (2012) 229-238.
- [4] D. Figueroa, M.J. Robinson. Hydrogen transport and embrittlement in 300 M and AerMet 100 ultra high strength steels. *Corrosin Science* 52 (2010) 1593-1602.
- [5] E. Kossoya, Y. Khoptiara, C. Cytermannb, et al.The use of SIMS in quality control and failure analysis of electrodeposited items inspected for hydrogen effects, *Corrosion Science* 50 (2008) 1481-1491.