VOLVO

Volvo Aero Corporation

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Dear Mr. Conroy,

Volvo Aero Corporation is pleased to provide its submission regarding the accident involving Delta Airlines flight 1288, July 6, 1996.
Volvo Aero's submission is a report that summarizes the test program which was developed to identify the root cause of overheated / defective microstructure in titanium holes. Details of the manufacturing parameters, BEA inspection and metallography are included for each test hole.
Results and conclusions in this submission have been reviewed with P&W peronnel.

Volvo Aero appreciates the opportunity to have participated as a party to the investigation and hopes that the enclosed report will be of assistance as the Board concludes its investigation.

Sincerely

[redacted]

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for Mr. Lennart Thore'n
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SUMMARY OF DRILL TESTS DONE IN JT8D HUB MADE OF TITANIUM 6-4.

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Sammanfattning/Abstract

Drill tests have shown that overheated/work hardened microstructure can be created during rough drilling, but not during subsequent boring and honing operations. The drill tests have shown that it is difficult to have overheated/work hardened microstructure remain after fine boring and honing. The only method during the test to achieve this is to remove less material than normal in the fine boring and honing operation.

To get a defective microstructure, high local heat in combination with heavy deformation is required. This can be achieved by accumulation of chips. All damages in the holes have been created in the rough drilling which have been performed by forced tool breakage and by forced accumulation of chips. The rough drilling has been done by cutting without coolant and/or by higher cutting data than used in production.

Microstructures and surface layer similar to the failed hub have been obtained in hole #2B and #57.

During abusive drilling, alloying can occur from the tool into the material of the part. Presence of foreign material on the surface can interfere with the anodizing, resulting in grey area within the BEA indication. By chemical analysis, it has been verified that in some of the holes, among others #2B and #57, show areas of iron (Fe) on the ID surface, resulting from this alloying process. The foreign material has caused grey areas within the BEA indications.

1. INTRODUCTION

This report is a summary of the metallurgical investigations that have been done because of the JT8-Hub failure of Delta Airlines flight 1288 in Pensacola Florida on the 6th of July, 1996.

A large number of holes have been drilled with the purpose to duplicate the defect of the failed hub; similar microstructure as the failed hub have been created.

2. ADDITIONAL INFORMATION

Test material: JT8-Hub Front parts made of Ti 6Al 4V, PWA 1228.

3. TEST PROCEDURE

The normal operation to manufacture tie rod holes and counterweight holes in the JT8-hub is rough drilling, fine boring and honing.

All damages in the holes included in this report have happened during the rough drilling which has been performed by forced tool breakage and by forced accumulation of chips. The rough drilling has been done by cutting without coolant and/or by higher cutting data than used in production.

The tests have shown that it is difficult to have any remaining overheated/defect microstructure after fine boring and honing and still meet the surface finish requirements. This has only been possible to achieve with less material removal than normal in the fine boring and honing operation.

All of the test holes have been Blue Etch Anodized (BEA).

4. RESULTS

4.1 Hole #2B

The hole was drilled with high speed steel drill (HSS) without coolant to breakdown (see photo 1).

Except for the area quite close to the location of the drill breakdown and the plane shown in photo 1 the microstructure shows deformation in proportions considered to be normal for a rough drilled surface.

No fine boring and honing have been done.

The area quite close to the location of the drill breakdown shows a micro-structure, in the surface layer, with an appearance similar to the failed hub. The microstructure in the surface is heavily deformed and have a hardness of up to 53 HRC which correspond well with the values for the failed hub (see photo 2).

The hardness is converted from HV to HRC.

The cross section shows a deformed microstructure to a depth of up to 0.5 mm which covers about 2/3 of the hole in the circumferential direction. The microstructure could be affected rather deep because of a local heat distribution in circumferential direction (see photo 3).

The generated surface layer is very brittle and contains several cracks (see photo 4 and 5).

The surface layer has a lamellar structure. Chemical analysis shows that the surface layer contains a high concentration of iron (Fe) from the drilling operation. The presence of iron in the material is explained by alloying during the drilling (see photo 6 and concentration profile on page 4 in the appendix).

Anodizing in BEA can be obscured by foreign material on the surface which can be seen on the cross section on photo 1. In this case the foreign material is iron (Fe) and the indication appears in the grey scale.

4.2 Hole #2

The hole is drilled with standard cutting data with HSS drill (see photo 7). The indications from BEA have been investigated and they consist of impressions of chips smeared on the hole surface. Longitudinal sections through two of the BEA indications show plastic deformed material to a depth of up to 35μm (1.38 mills), created by impression of chips (see photo 8-10).

The deformed area will be removed in the following fine bore operation where the material removal normally is at least 0.3 mm (0.012 inch) on the ID surface.

4.3 Hole #26

The hole is drilled with standard cutting data with HSS and then fine bored. No honing has been performed (see photo 11). The microstructure shows deformed material to a depth of up to 12μm (0.47 mills) (see photo 12).

4.4 Hole #25

The hole is drilled with standard cutting data with HSS, than fine bored and honed (see photo 13). The microstructure shows deformed material to a depth of up to 5µm (0.20 mills) (see photo 14).

4.5 Hole #1A

The purpose of this test was to investigate how overheated microstructure appears in BEA in normally drilled holes.

Adjacent to the normal manufactured hole #1A, a HSS drill forced to fail by increased cutting data and without coolant. The area of the drill failure did not appeared blue in BEA because of contamination of iron (Fe) by alloying during the failure, which interferred with the anodizing and gave a black/grey surface (see photo 15).

The adjacent hole mentioned above has not any S/N.

The drill failure caused a bulged area on the ID of hole #1A because of a considerable heat through the material. The bulged area in hole #1A was removed in the fine boring operation. After the fine boring and the honing an elliptic cavity could been seen in hole #1A.

Hole #1A was opened up and blue etched. The surrounding area of the cavity indicates alternately in grey and blue shade in BEA (see photo 16).

Longitudinal sections were cut out from hole #1A in area A and B, (see photo 16). The microstructure in area A exhibit remelted material with cracks and overheated material (above β-transus) with transformed β (see photo 17). In area B the microstructure shows overheating (above β-transus) with transformed β and partially transformed β (see photo 18).

4.6 Hole #1B

Like the previous item drilling with HSS was performed adjacent to the normal manufactured hole #1B. The drill was forced to fail by increased cutting data and by drilling without coolant.

The hole with the drill failure has not any S/N.

The drill failure in this case caused the same type of damages on the ID of hole #1B and almost the same response in the BEA in comparision with hole #1A (see photo 19 and 20).

A bulged area was formed on the ID in hole #1B but is less in proportion compared to hole #1A. The bulged area was removed in the fine boring operation. No cavity could been observed after the honing.

Hole #1B was cut to two pieces and then blue etched. In the heat affected area a BEA indication consisting of a mostly blue elliptic spot with a surrounding area in alternately in grey and blue shade (see photo 20).

The center of the BEA indication shows a crack (see photo 21).

SEM analysis has shown presence of iron (Fe) in the center of the BEA indication, which appear in the grey scale (see photo 21). As mentioned before, presence of foreign material such as iron can interfere with the anodizing process.

No sections for examination of the microstructure have been cut out from hole #1B but based of the similar appearance with hole #1A, remelted material (above β-transus) with transformed β may also occur in the indication area in hole #1B.

4.7 Hole #57

The hole was drilled with increased cutting data with HM (carbide) drill to breakage. It ~~was fine bored until the hole~~ surface was visually clean followed by honing. The cuttning in the fine boring and the honing operation is less than in production to prevent a removal of affected material.

The hole was blue etched and opened up. The drill breakage area exhibit a white-gray indication (see photo 22). The normally light blue to blue-grey color have been bleached by the coolant during the opening of the hole. After BEA reetch, the indication appears blue (see photo 23).

Cross sections were cut out from the indication area in hole #57. The microstructure shows deformation to a depth of 0.2 mm (0.0079 inch) (see photo 24). No remelted or overheated material (above β-transus) with transformed β have been found.

During the drill breakage particles from the tool have been pressed into the ID.

Some areas in the sectioned indication exhibit a microstructure with an appearance similar with the failed hub (see photo 25).

By chemical analysis the particles have been verified as tungsten (W). Presence of iron (Fe) has also been found in the area of the indication. This contaminations causes an interference with the anodizing and result in grey area within the BEA indication (see photo 26).

An interference of the anodizing due to contaminations may be the reason why the indication appeared white-grey at the first BEA and blue after reetch.

4.8 Hole #52

The hole was drilled with increased cutting data with HSS drill to breakage. It was fine bored until the hole surface was visually clean followed by honing. The cuttning in the fine boring and the honing operation is less than in production to prevent a removal of affected material.

The hole was blue etched and the drill breakage area shows a blue circumferencial indication. The hole was opened up and the two halfs were BEA reetched. The indication appeared in the same way after reetch (see photo 27).

Cross sections were cut out from the indication area in hole #52. The microstructure shows deformation and overheating to a depth of 0.6-0.7 mm (0.024-0.028 inch) (see photo 28 and 29).

5. DISCUSSION

The drilling tests have shown that it is difficult to have an overheated/defect microstructure remain after fine boring and honing. The only method during the test to achieve this is to remove less material than normal in the fine boring and honing operation.

To create a defective microstructure, high local heat in combination with heavy deformation is required. This can be achieved by accumulation of chips. An example of a heavy accumulation of chips on a Delta drill is shown in photo 30.

All damages in the holes have been created at rough drilling which have been performed by forced tool breakage and by forced accumulation of chips. The rough drilling has been done by cutting without coolant and/or by higher cutting data than used in production.

In two holes microstructure features similar to the failed hub have been found:

- Hole #2B was drilled without coolant with HSS to breakdown. No fine boring and honing were performed. The area quite close to the location of the drill breakdown shows a microstructure with a similar appearance as the failed hub. The microstructure at the surface is heavily deformed and a hardness up to 53 HRC has been measured in the deformed layer, which correspond well with the values for the failed hub.

- Hole #57 was drilled with increased cutting data with HM to breakage. It was fine bored until the hole surface was visually clean followed by honing. The cuttning in the fine boring and the honing operation is less than in production to prevent a removal of affected material. During the drill breakage particles have been pressed into the ID. Some areas in the indication exhibit a microstructure with a similar appearance as the failed hub.

BEA is a nondestructive test method for detecting metallurgical variations at the surface of titanium parts. The method was developed to detect metallurgical discontinuities such as segregation, but can also detect discontinuities such as overheating and tool marks.

Alloying can occur from the tool into the material of the part which can affect the microstructure.

Presence of foreign material on the surface may interfere with the anodizing which result in grey area within the BEA indication.Ti 6-4 has a light blue to blue-grey color after BEA. If a affected microstructure within a hole gives a grey signature because of foreign material on the surface, the indication can be diffucult to find and may require additional etch processing or metallographic replication.

By chemical analysis it has been verified that some of the holes, among others #28 and #57, have a presence of iron (Fe) on the ID surface because of the "alloying effect". The foreign material has caused grey areas within the BEA indications.