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Failure analysis of J85-CAN-15 turbojet engine compressor disc

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A R T I C L E I N F O

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A B S T R A C T

This paper analyzes the J85-CAN-15 engine damage due to fracture of the compressor disc 8th stage dovetail post. An Inner Object Damage (IOD) phenomenon was identified. The damaged compressor disc material is Incoloy 901 forging. The composition of the disc is determined as 42.7%-Ni, 34%-Fe, 13.5%-Cr, 6.2% Mo, 2.5%Ti, 0.1%-Cu, and 0.05%-C. The average hardness value of the material is 44 HRC. The burrs have been observed under Field Emission Scanning Electron Microscope (SEM) and they are considered as the origin of the fatigue on the engine compressor disc. The metallurgical analysis results show that manufacturing defect was propagated under the repeated low and high cyclic loads.

1. Introduction

Aviation manufacturing is known as a high-tech industry and a strong indicator of a country's industrial level [1,2]. Like all other high-tech industries, aviation has its own restrict rules and regulations. In the commercial side, these rules and regulations are generally governed by the international and local airworthiness organizations that are directly/indirectly dependent on International Civil Aviation Organization (ICAO) which serves to United Nations (UN). In the military side, naturally, the airworthiness organizations are the organic parts of the military hierarchy. The aircraft, engine, and other component manufacturers and users have to follow these regulations promptly. It is worth emphasizing that many tests are made for approving the parts that are safe enough to be used on the aircraft or its components. Manufacturing an airborne part is difficult and it requires many tests until it is approved as flight-ready-part. Obviously, every test process has its own limitations which may lead to miss the manufacturing defects; finally, these defects may end with undemanded incidents/accidents.

The poor planning, erroneous design, faulty manufacturing, and assembly may be the reason for defects. With the usage of high-tech detection devices, it has been figured out the impulse of the cross-sections and notches might be the core reasons for stress concentration that still encountered in the manufacturing industry [3]. These defects may be encountered in aircraft engines also.

On the other hand in the open literature, there are studies regarding fatigue in aircraft engines. The studies are given as follow:

Seon-Gab Kim et al. [4] investigated the crack of the turbine blades of the J85 engine. It has been claimed that in the mentioned study, the problem was the secondary cracks of the blades due to overstress. Multiple cracks were found under SEM with some peelings. In conclusion, it was determined that the engine suffered failure because of a long operating time.

Bok-Won Lee et al. [5] investigated a fretting fatigue in the J85 engine 1st stage compressor blade's tang region under Low Cycle Fatigue (LCF). There are three tangs on the bottom side of the 1st stage compressor blade. And the crack was initiated at the mating surface between a retainer pin and a pinhole of the center tang. With fractographic evaluation and Finite Element Method (FEM) analysis, they found that the occurrence of the highest stress over the inner surface of the middle tang rather than front and rear tang could be explained by the centrifugal force. In conclusion, they recommended an inspection procedure during the follow-on-support

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phase of the engine.

K. Anandavel et al. [6] made investigations on the dovetail region of blades. They compared the straight dovetail and 20^0 skewed dovetails. The effect of three-dimensional loading on macroscopic fretting has been investigated. At the conclusion of accurate prediction of the fretting aspects, a skewed dovetail configuration was found inevitable.

Considering the above-mentioned studies and other scientific studies in the open literature, the analyses are generally focused on the engine parts that are damaged for user origins. In this study, the manufacturer defect based investigation on the dovetail post surfaces of the compressor disc is carried out.

2. J85 Engines and compressor assembly

2.1. Information regarding J85 engine

The General Electric J85 family is based on a small single-shaft turbojet engine, that powers supersonic Northrop F-5/T-38 in military versions as well as in commercial CJ610 [7]. The engine features, an eight-stage axial-flow compressor powered by two turbine stages. The J85 engine compressor's efficiency is 82.2% and the pressure ratio is 8.3. The burning efficiency of the combustor chamber is 98.2% and the nozzle efficiency is 97% [8]. With these features, J85 family engines can be considered as an effective engine. This effectiveness makes J85 engines on the most demanded engines in the aviation industry with the number of 13.600 total manufactured engines from 1954 to 1988.

Basically, as it is depicted in Fig. 1, a single-shaft turbojet engine features compressor, combustion chamber, shaft, turbine, propelling nozzles, and afterburner sections [9].

2.2. Engine's compressor

Also, the compressor and compressor blades are the core sections of the study as shown in Fig. 2.

Mainly the compressor increases both the pressure and temperature of the air. Work input is required to achieve a specific pressure ratio. Depending upon complexity the turbojet compressor pressure ratio ranges from 4:1 up to 25:1 [11]. The J85-CAN-15 engine has an eight-stage axial compressor as mentioned before.

3. Material and method

During take-off roll while about 100 Knot of speed, the pilot terminated the flight because of a stall signal from the left engine. Later on, the engine was controlled by the technician physically. The damage was seen visually so the engine was removed and sent to the engine shop. The founding was the fracture of a dovetail post from the 8th stage compressor disc. With the result of fracture, two blades from each side of the post were removed. And finally, all debris particles damaged the 1st and 2nd stage turbine blades irreparably.

3.1. Visual examination

In the shop, the whole engine was disassembled. Firstly upper casing assembly as shown in Fig. 3.a and lower casing assembly as shown in Fig. 3.b were examined in terms of seal gap, sector vane assembly and clearance, vane sector tip clearance measurements, and incorrect assembly of vane sector. No defect has been detected on both casing assemblies.

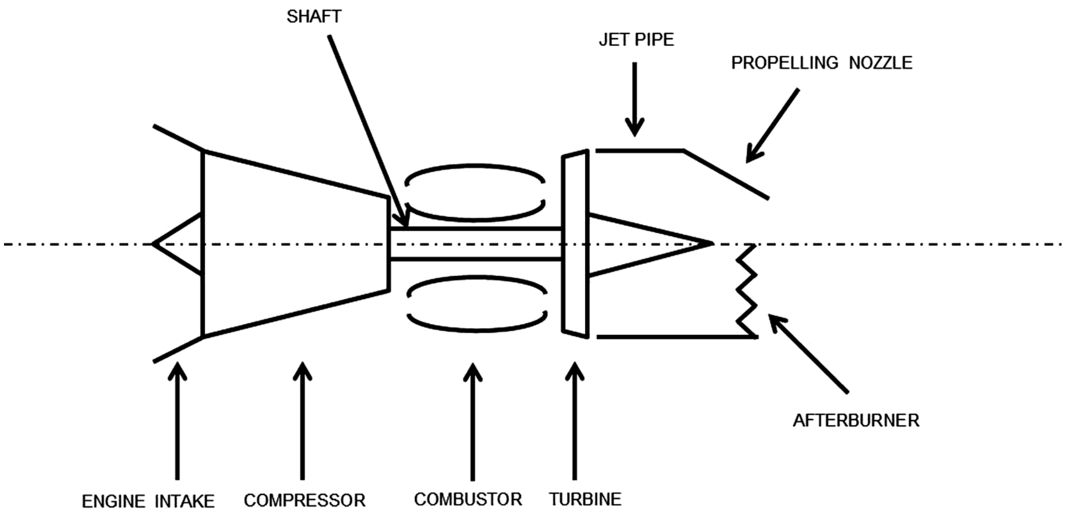

Fig. 1. Sections of the Single-Shaft Turbojet Engine.

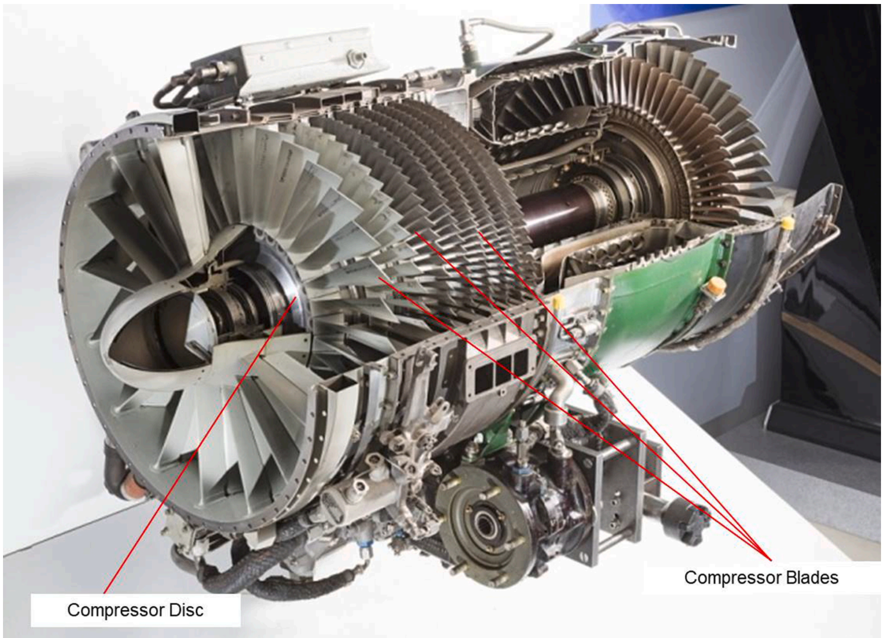

Fig. 2. Compressor Disc and Blades [10].

After casing assemblies, the Main Frame assembly and Exit Guide Vane (EGV) that are shown in Fig. 4, were inspected in terms of debris originated malfunctions. No malfunctions and defects were encountered during the inspection.

Respectively, the next assembly was the compressor rotor module. The controls were made in terms of clearance dimensions of discs, spacers, driveshaft, blades, and blade tips belonging to the compressor rotor module. No defects were detected, from 1st to 7th stage blades of the compressor discs. But on the blades on the 8th stage, the fractures are significantly identified as they can be seen in Fig. 5. It is considered that the most probable reason for the fracture is the removal of the two blades from their places because of the damaged dovetail post.

Almost all 8th stage compressor rotor module turbine blades tip section had fractures as shown in Fig. 6. The fractures were determined averagely 1/5 of the way down from the tip, and the rest of the blades had partial damage such as rubbing, and leading & trailing edge nicks. Therefore it was determined that the problem originated from the 8th stage compressor disc dovetail post region fracture. The tow removed compressor blades and debris particles had damaged the 8th exit EGV segments, 1st and 2nd stage turbine nozzle besides 1st and 2nd stage hot section turbine blades.

Under, Non-Destructive Inspection (NDI) tests, a Fluorescent Penetrant Inspection (FPI) was carried out on the dovetail post areas of the 8th stage disc for detecting the cracks or out-of-limit notch damages. As a result, no NDI solution remains were detected in the applied regions. Also for the mentioned regions, a Magnetic Particle Inspection (MPI) was applied. No newly occurred cracks were observed.

3.2. Fractographic examination

It is known that the discs are operated under low and high cycle loads. Hence, for the application of a further investigation of the

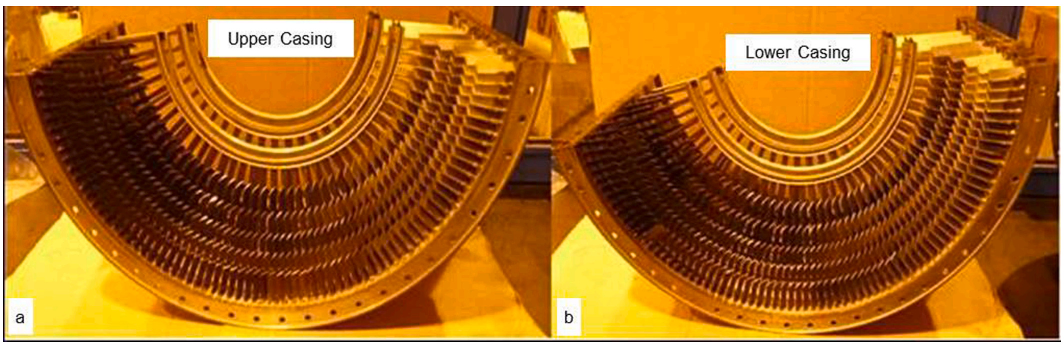

Fig. 3. a. J85-CAN-15 Engine Compressor Upper Casing Assembly, 3.b. J85-CAN-15 Engine Compressor Lower Casing Assembly.

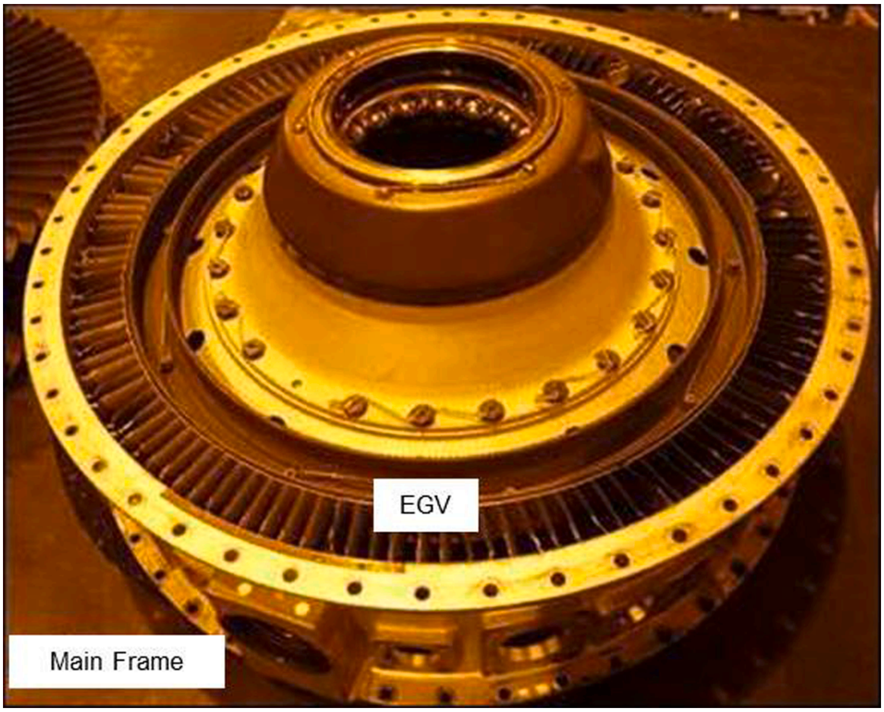

Fig. 4. Main Frame and EGV.

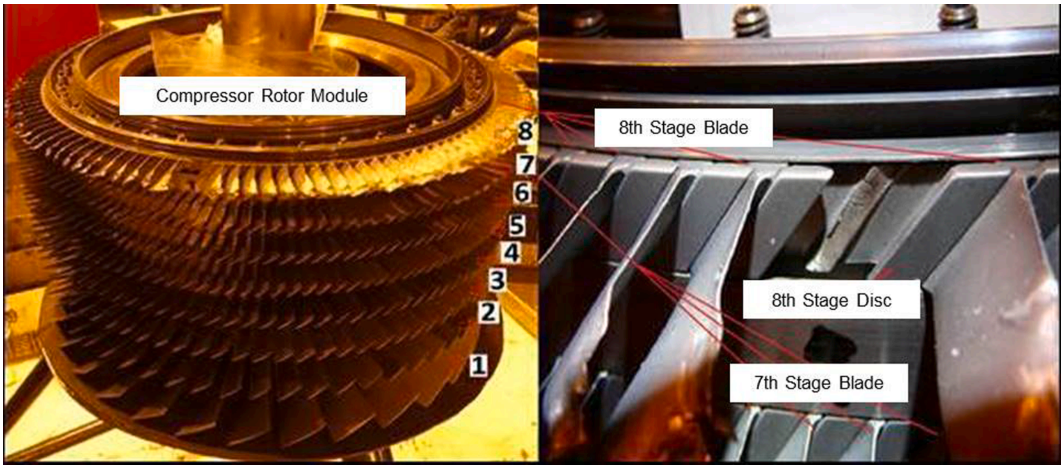

Fig. 5. Assembly of Compressor Rotor Module and 7th, 8th Stage Disc Blades.

defects which might be originated from manufacturing defect or usage conditions in pursuit of Low Cycle Fatigue (LCF) / High Cycle Fatigue (HCF), the variety of tests such as Field Emission Scanning Electron Microscope (SEM), Stereo Microscope, Micro-Hardness Test Device, and Image Analyzer applications were carried out.

It was observed that one of the dovetail post regions that operate under high tension was damaged fatally. The fractured surface is perpendicular to the disc vertical axis. It was also observed that there was no particular macro plastic deformation and fracture section surfaces were generally clean as it is shown in Fig. 7.

The fractured dovetail post area of the 8th compressor disc, shown in Fig. 8 was observed through a stereo microscope. A fretted surface was determined on the regions that are close to the fracture line and in the post where dovetail and blades are in contact.

Through SEM, some burrs have been observed on both fractured dovetail posts and the other posts as seen in Fig. 9, some other similar burrs have been seen on the front corner of the disc. These burrs were evaluated as they might be nucleated from machining processes such as broaching or chamfering.

It is known that the fatigue in metallic materials develops under three phases such as crack nucleation, crack propagation, and

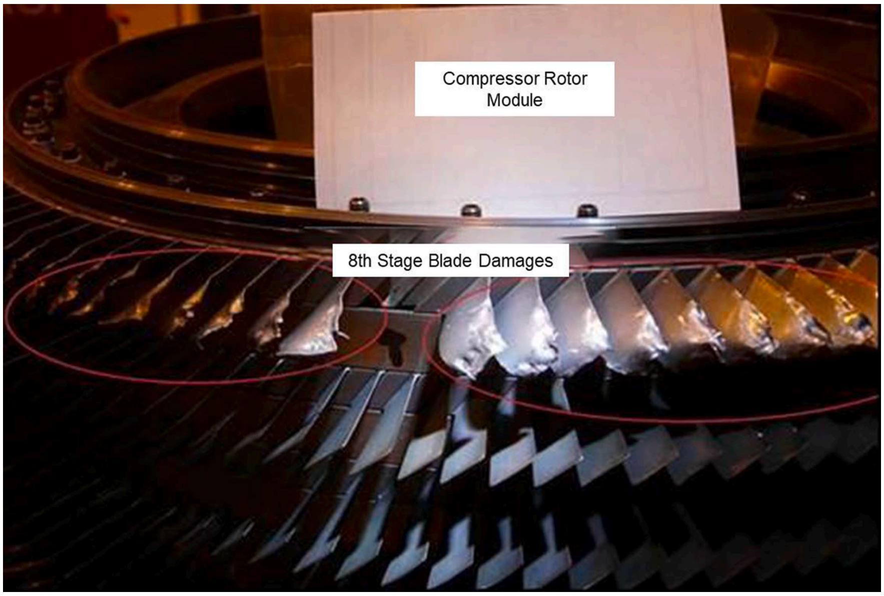

Fig. 6. 8th Stage Blade Damages on the Compressor Rotor Module.

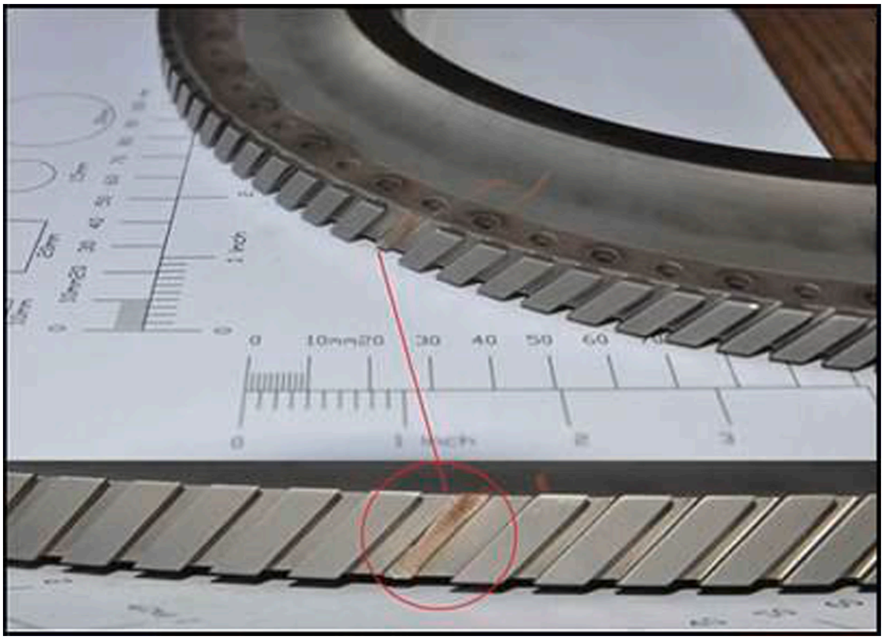

Fig. 7. The Disc Fractured Surface Section.

failure. Crack nucleation is the first step of the fatigue mechanism that sparks the whole process and can be emerged by the effect of environmental impacts. The machining process is one of the most important environmental impacts for the nucleation of the crack. Because all of the machining processes leave tool traces and/or scars on the material surfaces. It is worth emphasizing that, crack nucleation mainly locates at the plastic strain accumulation regions such as corner notches, nonmetallic inclusions, or crack-like defects [12].

Therefore, it is considered that the fatigue initiation process is nucleated from the burrs due to manufacturing defects and it is observed that the crack propagation had resulted in the ultimate failure.

During SEM investigations, some dimples were found as it is shown in Fig. 10. The considerations for the dimples are given below;

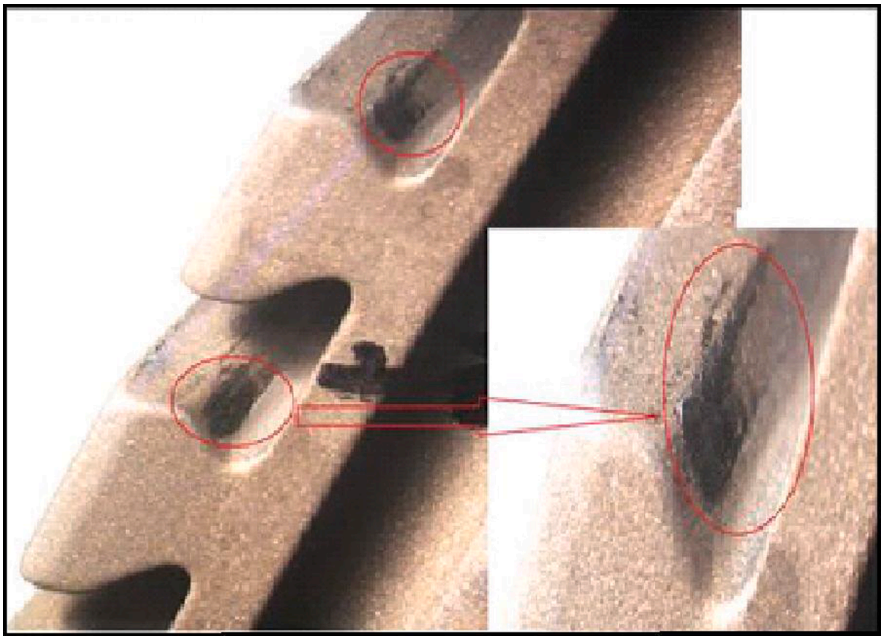

Fig. 8. The Fretting in the 8th Stage Disc Dovetail Post.

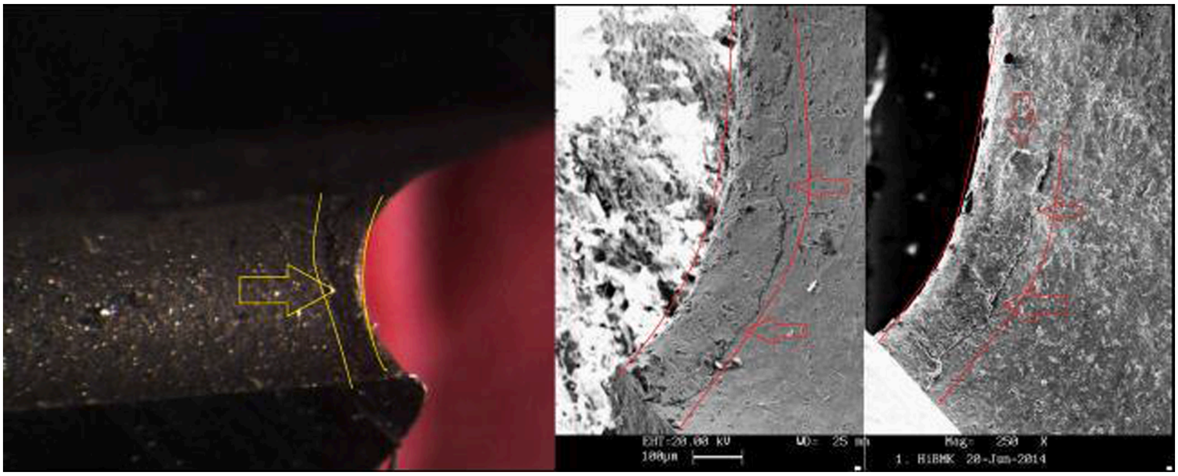

Fig. 9. The Burrs In The Entrance Section of the Dovetail Post.

- The starting point of these dimples is at the edge fillets and stressed regions where contain burrs which are thought to be originated from manufacturing defects.
- The dimples are located on the front outer part of the blade that close to the pressure surface on the disc and next to the corner cracks that are propagated in semi-elliptical form due to repeated loads.
- In the remaining limited regions, the dimples are formed as a result of ductile fracture with the effect of load.

The hardness variety is one of the most important indicators for fatigue analysis. Some measurements were done with the Rockwell Hardness Tester-C (RHT-C). The results of the measurements are provided below;

- The average hardness of the disc is 44 HRC,
- Testing of the parts that have the same part number the average hardness is 43 HRC,
- Testing on the manufacturing defected burr regions it is observed that the value of HRC is fluctuating between 38 and 48 HRC. It can be claimed that the possible reason for this fluctuation is originated from plastic deformation and the negative results of overheating.

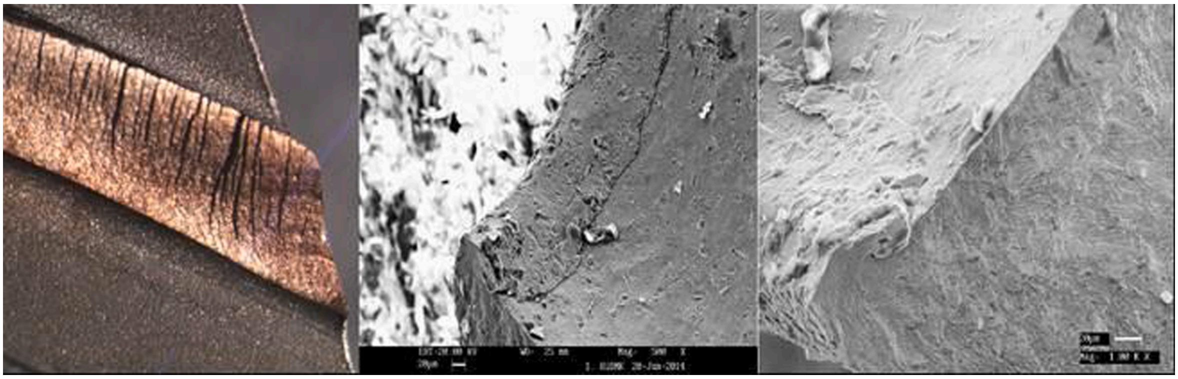

Fig. 10. Semi-Elliptical Corner Cracks and Pits Formed in the Fracture Section.

During investigations, a sample from the fractured line and two samples from dovetails were metallographically prepared for the optical microscope evaluation. The results are;

- As it is shown in Fig. 11, the dimensions of the burrs are ~ 170 μm in the axial direction and thickness is ~ 18 μm in the radial direction.
- No significant conversion was found other than the variation of fibrous direction that was originated from the burrs due to manufacturing defect.

4. Discussions

Above mentioned methods were performed for the determination of the fractured surfaces of disc dovetail post. The obtained results are given as follow:

- Due to high cycle fatigue under repeated loads, the crack propagates to a larger region
- (~95%) of the dovetail post surface.
- Disc dovetail post region is completely broken under overload as a result of not being able to carry loads over the remaining limited section (~5%).
- The crack, which was found at the intersection of the disc dovetail bottom radius and the frontal surfaces where the tension rises, was initiated from the corner part close to the pressure surface of the blade.
- It was concluded that the burr defect originating from the manufacturing process in the region where the crack occurred caused unstable changes in the hardness values of the material and facilitated the crack initiation with the additional notch effect.

5. Conclusion

After performing the cause analysis of the engine due to 8th stage compressor disc dovetail post, conclusions can be summarized as

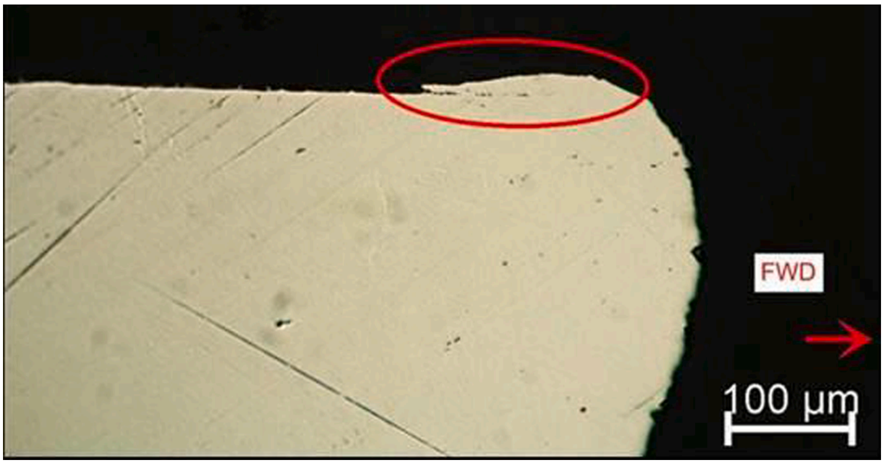

Fig. 11. Fibrous Dimensions Caused by the Burr due Manufacturing Defect.

follows:

(1) It was determined that fractures occurred in the material, the crack propagated with High Cyclic Fatigue (HCF) under repeated loads, and as a result, the dovetail post part of the 8th stage disc was broken when it could not bear the loads on the remaining cross-sectional region.
(2) As a result of the instability and notch effect in the material hardness values caused by the burrs on the dovetail post bottom radius part due to manufacturing defects, a fracture occurred on the dovetail post of the 8th stage compressor disc.
(3) With the removal of two blades from each side of the post damages happened on the compressor rotor blades, compressor stator vanes, and the EGV assy of the mainframe assembly.
(4) To prevent similar disruptions, all J85-CAN-15 engine compressor discs have been controlled for mechanical damages and imperfections.
(5) The manufacturer company was informed via technical coordination groups.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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