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A Study on Highly Porous Carbon-Carbon Aircraft Brake Disc using Air Coupled Ultrasonic

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Abstract
Carbon-Carbon (C-C) composites is a special class of ceramic matrix composites used in manufacturing of high temperature applications has excellent properties like high specific heat and thermal conductivity, lower in thermal expansion, good wear resistance and retention of mechanical properties. Inspection of these category of composite is a challenge as it possesses more of deceptive and attenuate. Air Coupled Ultrasonic (ACU) is used to over these inspection footraces. Evaluation of these Non Destructive Testing (NDT) results is a huge task involving expertise in manufacturing and NDT inspection. As Carbon-Carbon (C-C) composites is more attenuative and developing a standard / reference was more difficult and further evaluation on the actual aircraft brake disc becomes a mammoth task. Air Coupled Ultrasonic (ACU) inspection parameters were frozen and the brake disc are inspected and evaluated to the requirements of the approving authorities.

Keywords: Carbon-Carbon (C-C) composites, Air Coupled Ultrasonic (ACU), non-contact ultrasonic, aircraft carbon brake disc

1. Introduction

Composites of different types; ceramic, polymer and metal matrix are being used in aircraft industries for structures. These range of composites are being manufactured using chemical vapour infiltration, liquid metal infiltration, carbon-carbon composites, VARTM, autoclave moulding process. One of the important applications of C-C composites is the Carbon-Carbon aircraft brakes. This is in the form of multiple discs and are used in various civilian commercial aircrafts due to its excellent combination of properties like high specific heat, good thermal conductivity, very less co-efficient of thermal expansion, retention of mechanical properties at high operating temperatures and excellent wear resistant. Manufacturing of C-C brake disc is a mammoth task involving lot of time during development as the process of infiltration is very slow.

One of the challenges of Non Destructive Testing (NDT) is that these types of composites are generally more attenuated. Furthermore, ceramic composites have inherent porosity with multiple phases and degrees of non-uniformity. The porosity in Carbon-Carbon composites is in the range of 5 to 15%. Conventional water coupled ultrasonic technique is not feasible for the Carbon-Carbon composites due to the inherently high porosity levels. This paper describes the challenges faced in the Non
Destructive Evaluation (NDE) [1,2] followed for inspection of these C-C disc.

2. Manufacturing Process

Manufacturing of C-C brake disc is a cumbersome and time consumption process. Chemical Vapour Infiltration (CVI) and Liquid pitch/resin Impregnation methods [3,4,5] are two important methods for the manufacturing of C-C composites. The CVI process is gaseous process in which the hydrocarbon gases diffuse [6] into the carbon fibre preform and cracked high temperature and deposits the solid carbon on the fibre surface forming the carbon matrix. This a very also process, which takes about 3 months or more to get the C-C composite of required density. The other process involves a repeated impregnation and carbonation of carbon fibres preforms with carbon rich materials like pitch or resin. Several cycles of impregnation and pyrolysis is required to get the required densities. These process are the densification processes, and there always a residual porosity at the end of the process, the amount which depends on the final density of the product. This porosity makes the C-C products more attenuating and challenge to carry out the NDT especially the ultrasonic based ones [7,8].

3. Results and Evaluation

Non Destructive Evaluation process is being followed using Air Coupled Ultrasonic (ACU) technique have been used with very high power and low frequency ultrasonic transducer [5,9] for specific inspection requirements. Evaluation of the NDT results requires knowledge in the manufacturing process as well as analytical capability of Non-Destructive Evaluation. The C-C disc is having minimum thicknesses of 1.0” with/without cut-outs. Since the C-C disc is highly porous and the thicknesses are higher, the most feasible method of inspection is through transmission Air Coupled Ultrasonic (ACU) technique.

3.1 ACU Inspection: High transduction Non-Contact Ultrasound Second Wave™, Ultran system [8,9,10] is being used for inspection of the C-C brake disc. This system is built to suit the inspection of highly porous composite components [11,12,13].
ACU techniques have been used for inspection of C-C disc with the following parameters based on the iteration conducted during experiments:

- **Frequency** – 500 KHz
- **Voltage** – 325 volt
- **Burst** – 2
- **Gain** – 75 dB
- **PRF** – 100 Hz
- **LPF** – 800 KHz
- **HPF** – 80 KHz
- **Scan resolution** – 1 x 1 mm
- **Scan speed** – 50 mm/sec
- **Index speed** – 20mm/sec
- **Ambient air path between transducer faces** – 85mm.

The parameters followed for inspection produce lot of noise resulting in difficulties in receiving the flawless signal for analysis. Signals received on a good healthy C-C disc [14] have less amplitude due to inherent property of the material; it is difficult to differentiate the signal on C-C with porosity on a good region and porous region. By ACU, different category discs were inspected and evaluated. The NDE results have given vital information for the improvisation of the process to achieve the desired final quality.

During this experiments many C-C brake disc have been inspected and evaluated.

### 3.2 C-C brake disc analysis:

C-C brake discs were processed through Resin/Pitch impregnation and pyrolysis route. The disc densities were increased by subjected to densification cycles which involves repeated impregnation and pyrolysis cycles. The discs of different densities are obtained by carrying out different No. densification cycles. It has been observed that, when the disc is densified
beyond certain extent, the micro cracking has occurred within the discs [15]. The occurrence of micro cracking within the disc is actually revealed in the NDT. This gives an excellent input that up to what level of densification can be achieved without damaging the discs.

Many number of C-C rotor brake disc with cut out was inspected and evaluated. The brake disc which has very less porosity considered as good sample. Based on the qualitative approach methods the other disc was evaluated and qualified. The C-C disc having highly porous when compared with good disc is shown in figure 2. In the highly porous disc the micro porous are accumulated during infiltration process of manufacturing led to weaken the disc when compared with good one. Based on this exercise confidence level was build-up to inspection any level of porous with different thickness can be inspected and evaluated. The stator disc with cut out in the ID of the C-C brake disc. Few discs were without cut out too. In the stator disc shown has very high level of porous when compared with the good stator disc in figure 3. It is observed that the peak to peak scale of the ACU image the highly porous disc in the range of 31 to 35 dB, but the good disc has peak to peak attenuation levels of 16 dB. This wide range of dB levels brings out the differences between the good and porous disc which is predictable phenomena.
4. Conclusion

The C-C disc manufacturing process was stabilized to attain very less porous disc of rotor and stator for its intended application. NDE is the backbone of this process improvement towards production standards. During this process the NDE procedure and parameters were also iterated in identification of porosity and other defects. NDE analysis play a crucial role in the acceptance of the CVI manufacturing process of C-C brake disc for aircraft applications. Based on the criticality of the disc i.e very high porous disc, the disc was reprocessed for further improvement to reduce the porosity level. This was carried out based on the NDE analysis report. Due to this exercise the rejection rate was reduced and led to cost saving and production time of the programme.

References


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