MECHANICAL STRENGTH EXPERIMENTS OF CARBON/CARBON BRAKE DISK

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SUMMARY: The strength test was done for the Carbon/Carbon rotor disk which is the critical part of a carbon/carbon brake system in an operating time. The loading fixture was designed for the static strength test of a single carbon/carbon brake disk using finite element analysis. To simulate the real dynamic system in a static condition, the friction surface of the rotor disk was fixed and static load was applied to the rotor slot in the circumferential direction. The described failure mechanism of the brake disk can be described as matrix cracking occurred first at the contact surface of the rotor slot, subsequent delamination from the cracked contact surface, and the final fracture at the notch of the rotor.

KEYWORDS: Carbon/Carbon Brake Disk, Carbon/Carbon Strength Test, Delamination

INTRODUCTION

Carbon/Carbon disk material has several merits such as excellent thermal, structural stability and high specific stiffness, strength. Carbon/Carbon brake system converts a kinetic energy to thermal and frictional energy until the aircraft stops. Fig. 1 shows the configuration of the brake disk system that consists of pressure plate, 3 rotors, 2 stators and end plate. When an aircraft is just landing, the rotor disks are rotating with a wheel and tire also the pressure plate, stators and endplate is fixed at wheel axis. When the brake system starts, a hydraulic pressure add to the pressure plate. The friction between the disk gap induced by the pressure makes the aircraft stop. This pressure is changing with the time to maintain the axis torque uniformly. This uniform torque is equivalent with the reaction force at the rotor slot.(show in fig. 2) This reaction force leads to failure of the rotor disk. Also the uniform torque induces the uniformly accelerated motion of the rotor disk. As shown Fig. 2 the detail part of the brake disk consist of chopped-map and fabric. Both sides

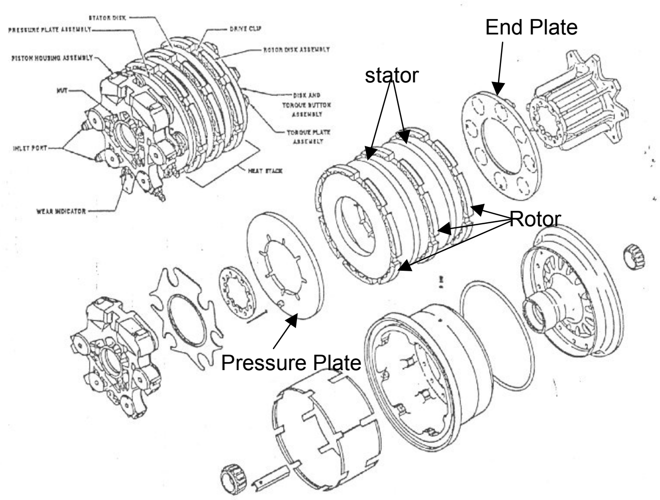


Figure 1 Assemble of C/C B/D system.

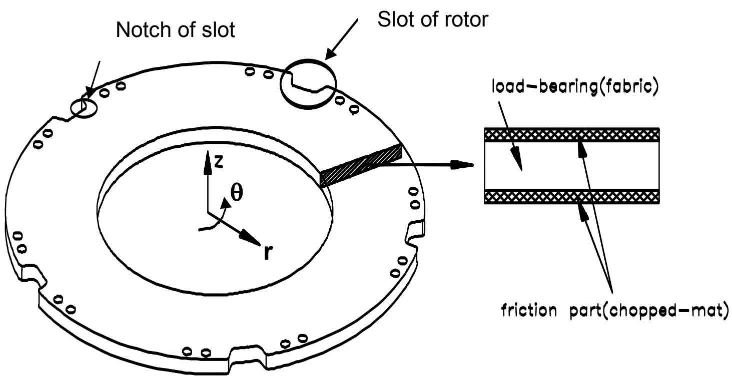


Figure 2 Shape and Corss sectional view of C/C B/D.

of the disk consist of a chopped-mat that emits a heat from friction surface. Also the core part of the disk consists of a fabric that sustains the braking loads.

During the development of the brake disk system, it is necessary to carry out the mechanical behavior and failure test for the brake disks. From this test results, we can design the brake disks having the better performance. This test can be divided into two steps. One is a coupon test to know the mechanical properties of the brake disk. The other is a structural test to know the failure load of the rotor disk. To know the failure load of the rotor disk, we can safely design the rotor disk.

In this study, The loading fixture was designed for the static strength test of a rotor disk and designed by finite element analysis to describe the similar boundary condition with real loading condition. The strength test was done for no metal clip rotor disk.

Loading fixture design

Table 1 Material properties of C/C B/D.

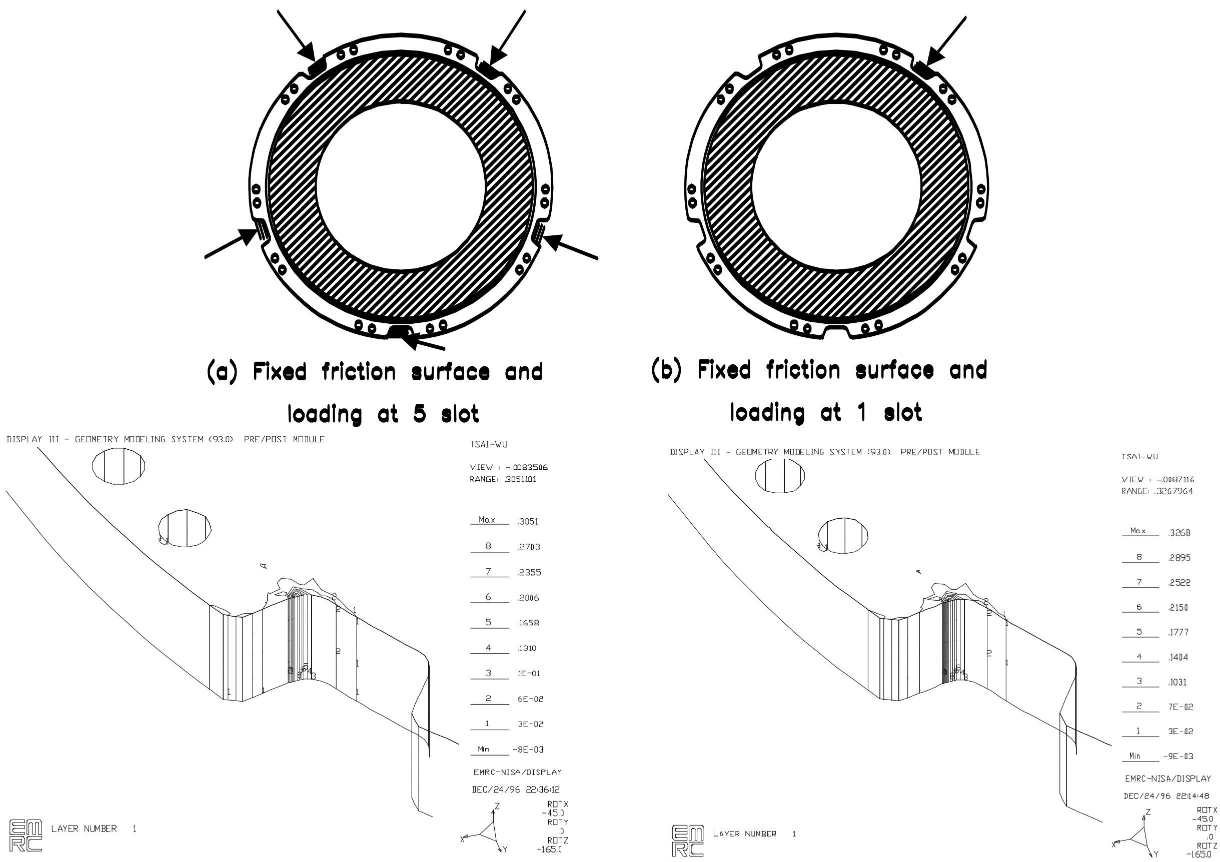
Properties	Symbol	value
Elastic modulus in r, θ	E_r, E_θ	*59 GPa
Elastic modulus in z	E_z	*3.46 GPa
Shear modulus in r-θ	$G_{r\theta}$	2.41GPa
Shear modulus in r-z	G_{rz}	1.38GPa
Shear modulus in θ-z	$G_{\theta z}$	1.38 GPa
Poisson's ratio	$\nu_{r\theta}$	0.3
Poisson's ratio	ν_{rz}	0.2
Poisson's ratio	$\nu_{\theta z}$	0.2
r-dir. Tensile strength		*103 MPa
r-dir. Compressive strength		* 90.1 MPa
θ-dir. Tensile strength		* 103 MPa
θ-dir. Compressive strength		* 90.1 MPa
z-dir. Tensile strength		* 3.01 MPa
z-dir. Compressive strength		* 118 MPa
r-θ planeShear strength		34 MPa
r-z planeShear strength		24 MPa
θ-z planeShear strength		24 MPa

*: material properties measured from material testing.

The FEM analysis for the design of loading fixture was performed by NISA-II that is commercial FEM code. The material properties used this analysis is shown in Table 1[1]. The object of this analysis designs the load fixture similar with a real loading condition. The load mechanism can be described to dynamic equilibrium having a constant angular deceleration. The dynamic equilibrium equation as follow.

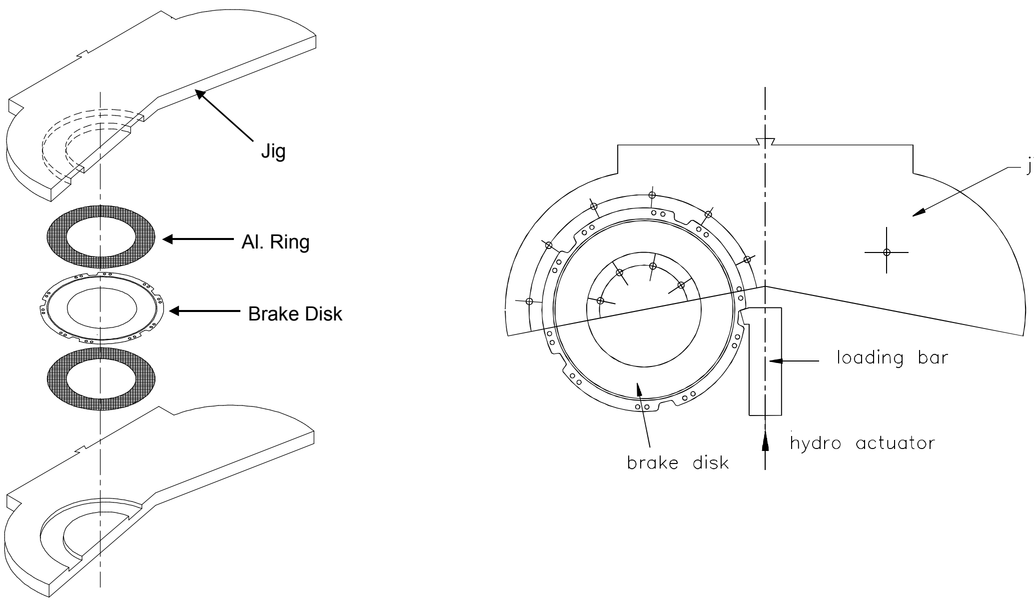
$$\sum M_z = I_z \dot{\omega}$$

In this equation, the product of mass inertia moment and deceleration can be ignored because it is 0.1% by comparison with the reaction moment. Therefore we can describe the dynamic equilibrium to the static equilibrium. We can get the failure load of the rotor disk by fixing the friction surface and adding the static load to the circumferential direction. To simulate the real boundary condition, we must fix the friction surface and add the load to the circumferential direction at all slots of the rotor disk. However, it is difficult to make a loading fixture which is satisfied the real boundary condition. So we designed the similar the loading fixture using the FEM analysis as shown in figure 3. As this results, The results of figure 3(a) and figure 3(b) are coincident each other. This results show that the loading acting at a slot doesn't affect other slots. Therefore, we designed the loading fixture as shown in figure 4. The loading fixture is composed of three parts that is composed of upper jig, loading bar and aluminum ring. The upper jig fixes the rotor disk. The loading bar transfers the braking load. The aluminum ring directly contact the friction surface of the rotor disk and fixes the friction surface of the rotor disk.



(c) Fixed friction surface and loading at 5slot **(d) Fixed friction surface and loading at 1slot**

Figure 3 Comparison of failure analysis for various b.c.



(a) slide view **(b) side view**

Figure 4 Configuration of static strength test jig for C/C B/D.

Static strength test

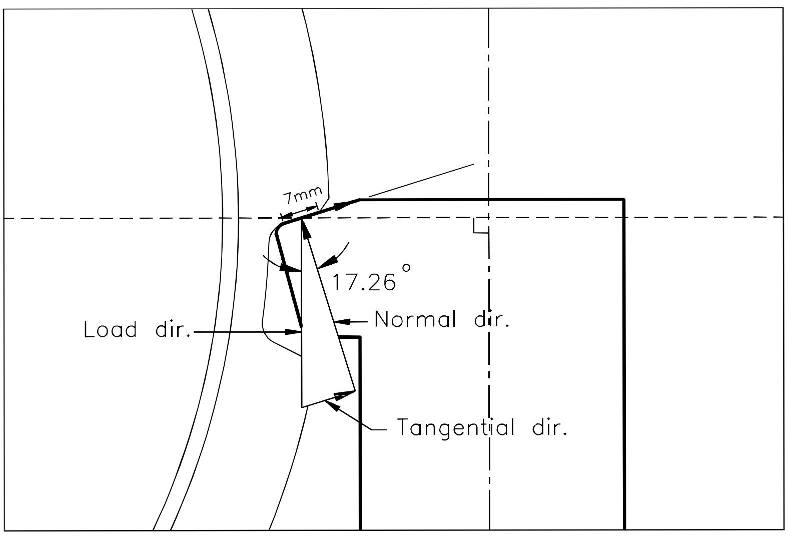
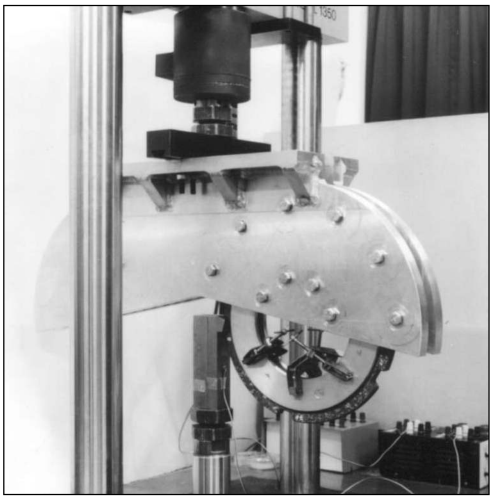


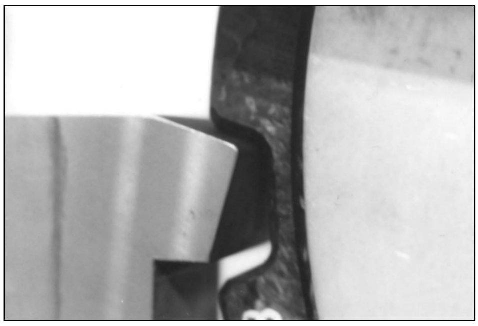
Figure 5 Load direction and contact area.

The static strength test was done 7 times for the rotor disks. The load as shown in fig. 5 is added to the circumferential direction for the rotor disk. The picture of test system is shown in fig. 6. The static strength test step as follow.

1) 1.5 mm/min load rate is used.
2) The contact length between loading bar and slot of rotor is 7mm from ending point of the slot notch as shown in fig. 5.
3) Execute the static strength test until the failure of the rotor disk occurs.



(a) side view



(b) detail view

Figure 6 static strength testing system.

Results

Table 2 Static Failure load of C/C B/D.

No. of specimen	Failure load(kgf)
1	1086
2	832.5
3	778.8
4	918.0
6	813.0
7	832.5
8	878.9
Average	877.1
Std. Dev.	102.5

The static failure load of the rotor disk is shown in table 2. Also typical load-displacement graph is shown in fig. 7. In the rapidly falling load point at fig. 7, we can observe the delamination soon after the matrix cracking of the contact area. In the figure 5, A slip phenomenon can be taken place at the contact area because the contact area leans about 17.26 degree with respect to radial direction. This leaned surface divides the force on the contact surface into a normal and tangential force about the contact surface. This tangential force causes a slip phenomenon. Such the slip phenomenon occurs not only at the static strength test but also the real break system. Wheel drum restrict the slip displacement because it is a one piece. Despite of this slip phenomenon, the leaned surface reduces the load applied to the rotor disk. At the static strength test, Most part of the slip

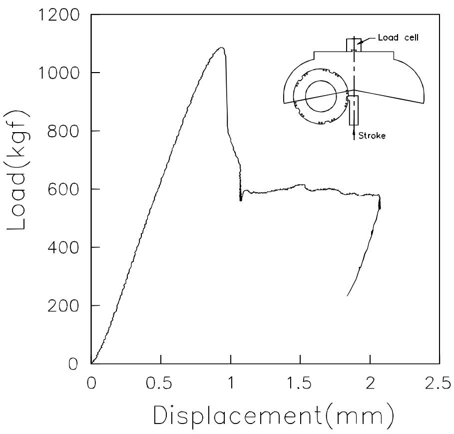


Figure 7 Load-displacement curve for C/C B/D static strength test.

Figure 8 C/C B/D after fracture.

displacement occurred at the static strength test jig. However, during the static strength test, the failure displacement of the rotor disk caused by the loading bar was within 1mm. Also the slip displacement was fairly less than the failure displacement. The typical failure aspect is shown in figure 8. Matrix cracking occurs at the contact surface and then delimination occurs through the circumferential direction. As this results, we can reduce the failure load to attach the clip retainer on the rotor slot. This clip retainer prevents the matrix cracking at the contact surface and the delimination from the contact surface.

CONCLUSIONS

In this study, the loading acting at a slot doesn't affect other slots. The static strength test fixture was designed for the static strength test of a single carbon/carbon brake disk using finite element analysis. We measured the static strength for a single Carbon/Carbon brake disk. The failure load of the disk was 877.1(kgf). When observing the typical failure mode, we detected the matrix cracking at the slot of the rotor disk. Soon after the matrix cracking at the contact surface of the rotor disk was occurring, the delimination was growing from the slot of the rotor disk caused by the matrix cracking.

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