Thermo-Elastic Analysis and Three-Dimensional Stress Analysis of Carbon/Carbon Brake Disk

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1. INTRODUCTION

Carbon/carbon(C/C) material has several merits in excellent thermal and structural stability, high specific stiffness and strength, high heat capacity and thermal transport. Therefore, C/C has evaluated as a versatile refractory material for new application since the debate of spacecraft. Especially, the C/C used for the brake disk has better thermal properties and mechanical stabilities at high temperature than steel material.

An aircraft C/C brake system converts kinetic energy to thermal and frictional energy until the aircraft stops completely. When the brake system starts to operate, hydraulic piston adds the imposed loading to the pressure plate, and the friction between the stator and rotor disk dissipates the kinetic energy and make the aircraft stop. This pressure changes with time to maintain the axial torque constantly. The constant torque is resisted by the reaction forces at the slots of rotors and induces the constant angular deceleration of the rotor disks. With this force, because of friction, very high temperature occurs during braking. At this load state, the airplane brake system needs very high stability. So the stress analysis of the airplane brake system is essential.

For this study the mechanical properties of C/C were measured. In order to find the pressure and temperature state during braking, thermo-elastic analysis was performed. Finally 3-dimensional stress analysis of a rotor was performed with this load state. From the analysis result, the geometry of rotor, which is safe from fail, was suggested.

2. MECHANICAL PROPERTIES OF C/C

Table 1 Mechanical properties of C/C.

	Symbol	B-32	B-52
Stiffness	$E_x = E_y$ (GPa)	59.3	19.2
	E_z (GPa)	3.5	6.2
	ν_{xy}	-	0.33
	G_{xy} (GPa)	17.4	6.8
	$G_{xz} = G_{yz}$ (GPa)	-	3.9
Strength	$X_T = Y_T$ (MPa)	103.1	69.1
	Z_T (MPa)	3.0	-
	$X_C = Y_C$ (MPa)	90.1	132.6
	Z_C (MPa)	118.0	126.6
	S_{xy} (MPa)	53.7	70.2
	$S_{xz} = S_{yz}$ (MPa)	5.7	35.1

The mechanical properties of C/C were measured. Test specimens were sampled from B-52 model of F-16 airplane. In order to enhance mechanical properties in thickness direction, the disk of B-52 was strengthened in thickness direction by stitching, which is different from B-32[1], 2-dimesional lay-up model of Korea Aerospace Industry(KAI). By the result, in-plane properties were weakened and thickness direction properties were enhanced generally.

3. THERMOELASTIC ANALYSIS

There are a number of problems to achieve the temperature or pressure distribution of the brake system during braking. Therefore, in this paper, analytical method was used to achieve the distribution. The sub-module of ABAQUS was used.

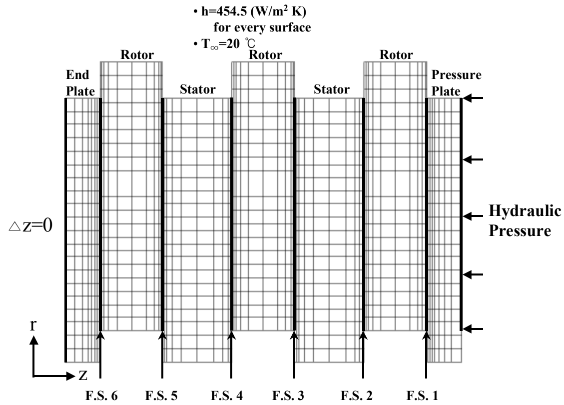


Fig. 1 Analysis model and its boundary conditions for the thermo-elastic analysis.

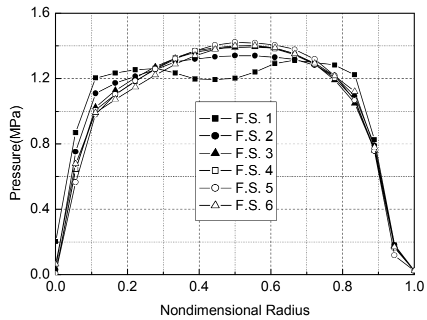


Fig. 2 Pressure distributions at each friction surface.

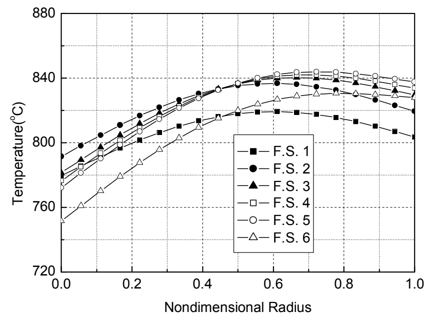


Fig. 3 Temperature distributions at each friction surface.

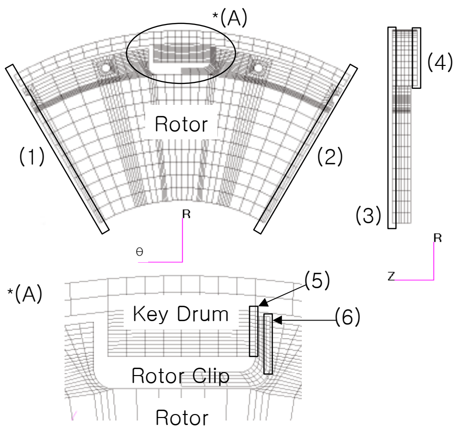
Table 2 Physical properties of C/C.

Density(kg/m^3)	1780	
Thermal expansion (ε /εK)	In-plane	1.15 x 10^{-6}
	Out of plane	1.63 x 10^{-6}
Thermal conductivity (W/mK)	In-plane	31.8
	Out of plane	25.9
Friction coefficient	0.2	

The analysis model is shown in Fig. 1. Table 2 presents the physical properties of C/C[2]. The hydraulic pressure and angular velocity history data were used from the dynamo test result. Initial angular velocity was 228 radian/second and system stop time was 20.23 seconds. The analysis was performed for every 0.1 second and maximum temperature appeared at 12 seconds. Figures 2 and 3 present the temperature and the pressure distribution of each friction surface when the maximum temperature appears.

4. Three-dimensional stress analysis for rotor

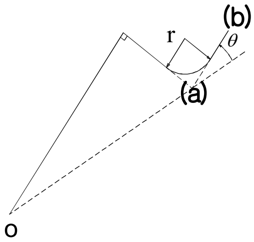
Three-mechanical stress analysis model and its boundary conditions are presented in Fig. 4. Because the pressure and temperature distributions of rotor were almost symmetric about the thickness direction, one half model of the rotor was used. The contact problems between rotor and rotor clip and between rotor clip and key drum were considered. Because the maximum pressure and temperature occurred on the 5th friction surface, pressure, friction force, temperature on the 5th friction surface were applied to the model.



(1) & (2) : Cyclic symmetry condition.
(3) : △z = 0.
(4) : △Θ = 0.
(5) : Contact surface between key drum and rotor clip.
(6) : Contact surface between rotor clip and rotor.

Fig. 4 Analysis model and its boundary conditions for the 3-dimensional stress analysis.

From the analysis result, the stress concentration appeared around the key hole of the rotor. For determining the rotor shape that is safe from failure, the stress analysis was performed as the variation of radius and rotation angle of contact surface at key hole part of the rotor. Due to the characteristics of C/C of pseudo isotropic nature of in-plane properties, the maximum value of Tsai-Wu failure index as stress transformation was used. Figures 6 and 7 present the failure index variation with respect to radius of curvature and rotation angle. The greater the radius of curvature or the more negative the rotation angle is, the greater the tendency for the failure becomes.



O : Center of the rotor.
θ : Rotation angle of the contact surface. (+ : counterclockwise)
r : Radius of the curvature.

Fig. 5 Definition of the rotation angle for the contact surface and the radius of curvature at the key hole.

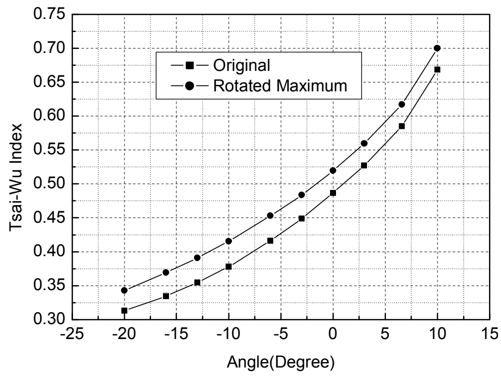


Fig. 6 Maximum Tsai-Wu failure index as rotation angle variation of contact surface at the key hole.

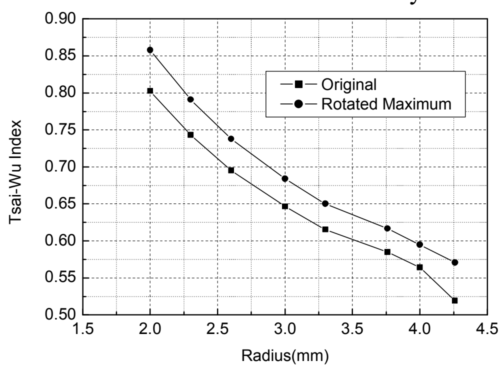


Fig. 7 Maximum Tsai-Wu failure index as the radius of curvature variation at the key hole.

5. Conclusion

The purpose of this study was to suggest the shape of rotor slot that is safe from failure. The mechanical properties were measured and thermo-elastic analysis was performed. And the analyses for various shapes of rotor were performed, so that the tendency of the failure index was studied.

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