THE ANALYSIS BETWEEN TENSILE LOADING AND VIBRATION MODE OF CARBON-CARBON COMPOSITE MATERIAL

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Abstract

Carbon-carbon composite material is a carbon fiber reinforced, and because of its high strength, elasticity and excellent heat-resisting property in high temperature, carbon-carbon composite material has been used in many fields such as aerospace, automotive industries, etc. Especially, aircraft brake discs used in aerospace can be cracked due to its fatigue and vibration under various loading condition. This research is focused on the influence of vibration of carbon-carbon composite material by using accelerometer with impact hammer excitation, and the change of vibration mode will be known by applying tensile loading test.
Keywords*:* Carbon/Carbon Composites, Tensile load, frequency, Vibration

1. Introduction

Carbon/carbon composite material is a material consisting of carbon fiber reinforcement, it is well-suited to structural application at high temperature (over 2500°C**)** and where thermal shock resistance and a low coefficient of thermal expansion are needed. Because of its excellent characteristics, carbon/carbon is widely used such as aircraft brake discs, and aerospace materials. The carbon/carbon material used as aircraft materials which can reduce the weight 40% if compared to other metallic friction materials; in the result the fuel saving can be obtained. [1] On the other hand, the carbon/carbon is made by stacking multiple laminates during manufacturing process. So the mechanics properties of composite materials are very different depending on the orientation angle. In addition, the tensile stress, friction on surface and vibration of brake discs simultaneously happened during takeoff and landing of the aircraft in braking system. The vibration of brake disc under tensile loading is very different from the vibration of brake discs that is not subjected to tensile loading. So, the change of vibration mode of Brake discs under tensile loading and the carbon/carbon brake discs which are being used in aircraft need to be proved for the safety. The tensile loading and vibration mode are considered for analyzing, and because there is a limit to accurately represent the actual behavior of the object, the ESPI (Electronic Speckle Pattern Interferometry) using contactless laser has been extensively researched. [2] Because ESPI technique uses the phase and the speed of light for experiment, it is affected by small vibration o movement of people and place condition. For that reason, accelerometer was directly mounted onto the object to measure vibration mode.

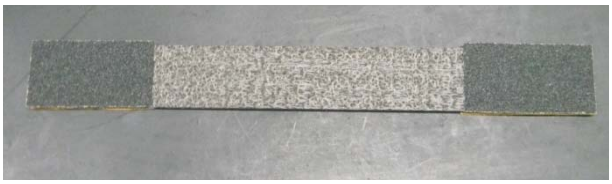
In this study, the carbon/carbon specimen in standard ASTM (American society for testing and materials) was chosen to observe the tensile strength during tensile testing and accelerometer was used to observe the change of vibration mode while the specimen was being experimented on the tensile testing machine. Furthermore, FEM analysis was also performed for comparing with the data obtained from the experiment. Thus the reliability of brake discs which is currently used can be predicted.

2. Testing method

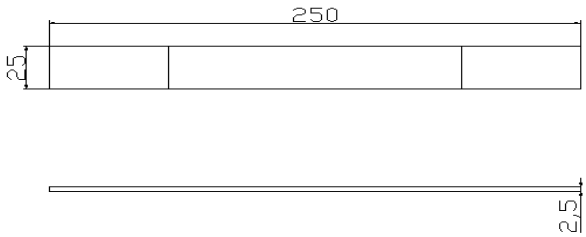
Tensile testing was performed to observe the change of vibration mode of carbon/carbon material during testing on the universal testing machine. The specimen type ASTM 3039 was chosen for this experiment. And 01bB-Metravib was used to measure the vibration mode by applying various tensile loadings. ANSYS workbench V12 was also carried out for FEM analysis.

2.1. Tensile testing

Fig.1 shows the carbon/carbon composite specimen (ASTM 3039) used for tensile testing.



(a) Real specimen



(b)Sketch of specimen (mm)

Fig.1 Carbon/carbon composite specimen

Specimen consists of carbon 0°/90° orientation structure. And to avoid location fracture at the loading point, the emery clothes were used. The loading speed was given 2mm/min for each experiment. [4]

2.2 Vibration testing

The maximum tensile strength of specimens was checked after the specimen totally fractured during tensile testing. In order to observe the vibration mode, eight specimens were experimented by applying tensile loading 0KN, 2KN, 3KN, 4KN, 4.3KN, 4.6KN, 4.9KN, and 5.1KN. Fig.2 shows the accelerometer which was being mounted on the specimen during tensile testing.

Fig.2 Experiment for vibration mode

2.3. FEM analysis

ANSYS Workbench V12 was performed for FEM analysis. In order to analysis vibration mode, Static structural analysis was connected to modal analysis. Fixed support was applied to the grip part on the both side of specimens. One side of the specimen was fixed and other side was moved in X direction. After fixing the Y, Z direction, 0KN, 2KN, 3KN, 4KN, 4.3KN, 4.6KN, 4.9KN, 5.1KN was applied in X direction to observe each vibration mode of specimens.

3. Results

3.1. Tensile testing

Three specimens of the nine was totally failure during tensile testing (see Fig.3). Fig.4 shows the maximum tensile strength of each specimen.

Fig.3 Failure of the specimens

Table1. Maximum tensile strength Vs Displacement

Specimen	Maximum tensile strength (KN)	Displacement (mm)
1	5.35	2.403
2	5.9	2.917
3	5.28	2.243

Table1. Shows the specimens in order 1, 2, 3 as shown in Fig.3.

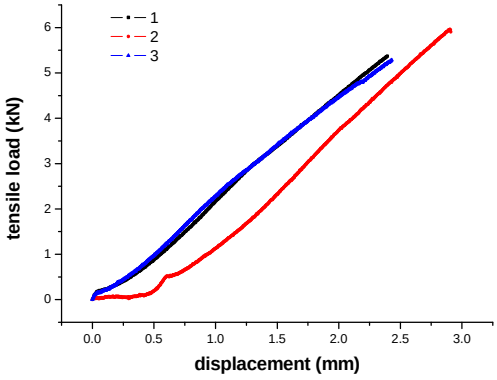


Fig.4 The result obtained from tensile testing

As shown in Table1, the results of tensile testing of the three specimens are different. The specimen will be cracked after exceeding the tensile load 5.28KN. Thus tensile loads that are not exceeding 5.28KN were applied for measuring vibration mode of the specimens.

3.2. Vibration mode analysis

3.2.1. FEM analysis

Table3. Shows the results obtained from FEM analysis.

Table3. Tensile load Vs Frequency

	Mode1	Mode2	Mode3	Mode4
0kN	215.69	593.27	1161.1	1915.9
2 KN	527.6	1116.3	1813.1	2647.5
3 KN	622.62	1294.7	2057.6	2941.2
4 KN	703.31	1448.7	2273.1	3205.4
4.3 KN	725.52	1491.4	2333.4	3280
4.6 KN	746.97	1532.7	2392	3352.7
4.9 KN	767.73	1572.8	2449	3423.7
5.1 KN	781.22	1598.9	2486.1	3470.1

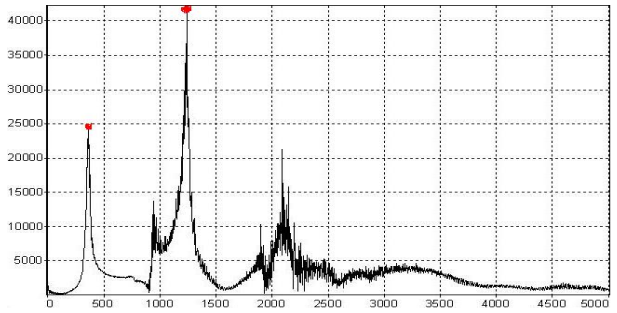
By looking at the above results of increasing the tensile load, it was found that the vibration also increased. The results between 0KN and 5KN are very different. The difference is 565.53, 1005.63, 1325, and 3274.2Hz.

3.2.2. Vibration analysis

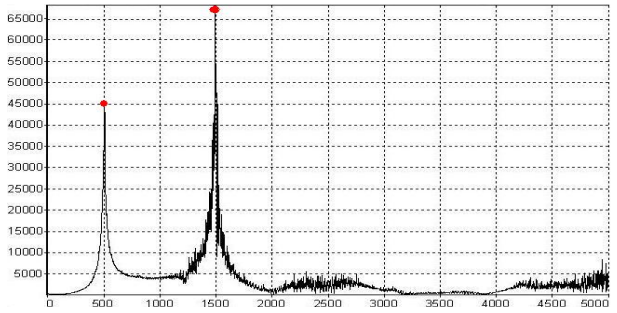
Table.4 shows the frequency of specimen obtained from the experiment under various tensile loadings and Fig.5 shows the graph of vibration mode.

Table.4 Frequency Vs Tensile loads

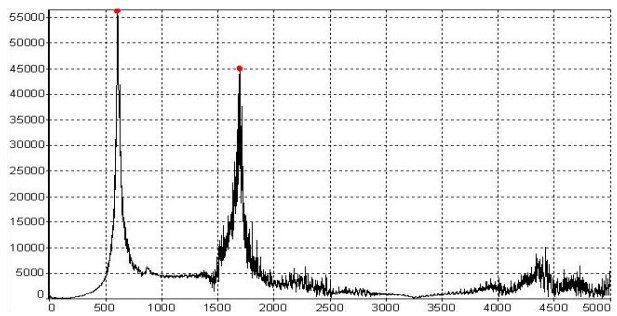
Tensile load (KN)	Mode1 (HZ)	Mode3 (HZ)
0KN	368.75	1250
2 KN	507.81	1490
3 KN	565.63	1589.06
4 KN	606.25	1717.19
4.3 KN	612.50	1740.69
4.6 KN	640.63	1785.94
4.9 KN	646.88	1796.88
5.1 KN	664.06	1803.13



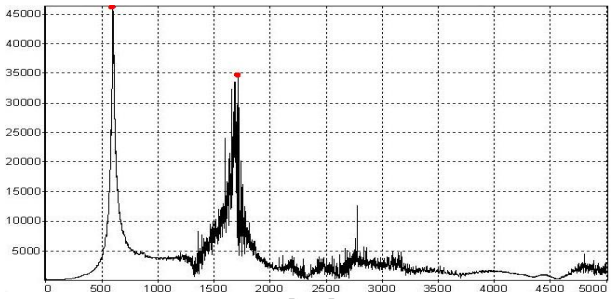
(a) 0kN



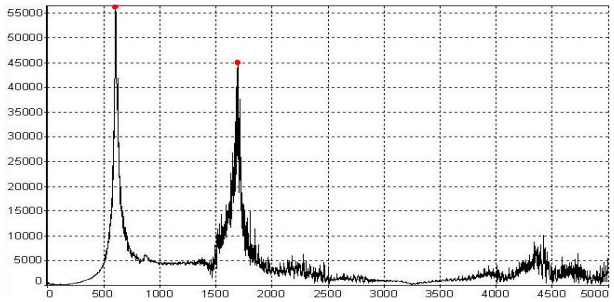
(b) 2kN



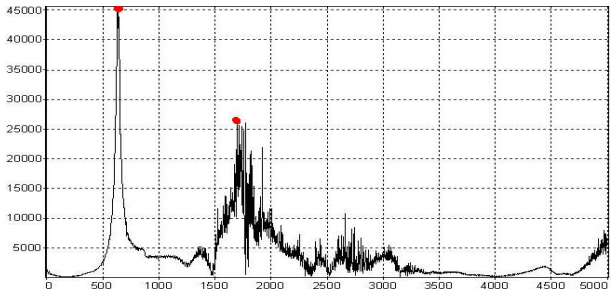
(c) 3kN



(d) 4kN

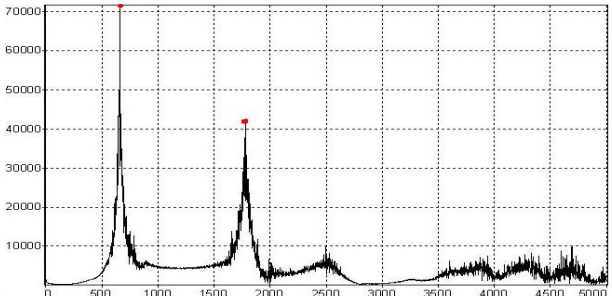


(e) 4.3kN



(f) 4.6kN

(g) 4.9kN



(h) 5.1kN

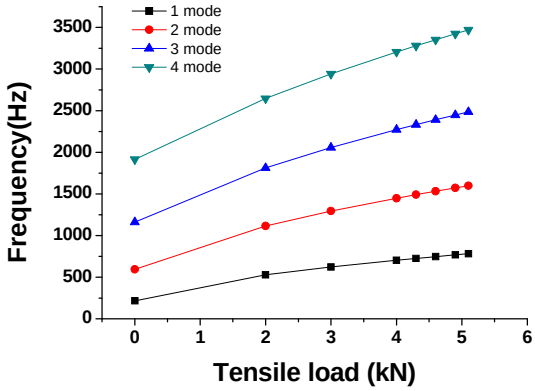
Fig.5 The graph of vibration mode

The above results show that each vibration mode of specimen changed under various tensile loads. And it was observed that the natural frequency was shown in the shift configuration. The reason can be proofed by the following equation.

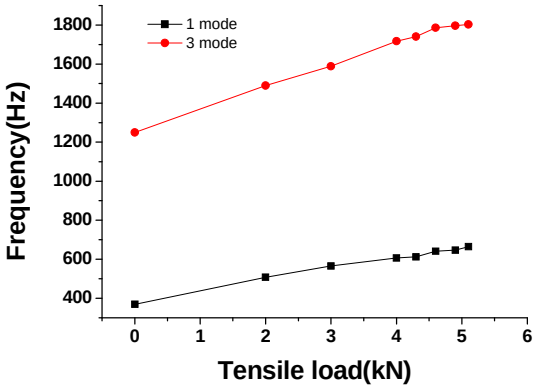
$$\omega_n = \frac{\pi^2}{l^2}\sqrt{\frac{EI}{\rho A}}\left(n^4 + \frac{n^2 P l^2}{\pi^2 EI}\right)^{1/2} \quad (1)$$

ω_n =Natural frequency (Hz), E= modulus, I= second moment of area, l = length, P= load, A= cross section area,

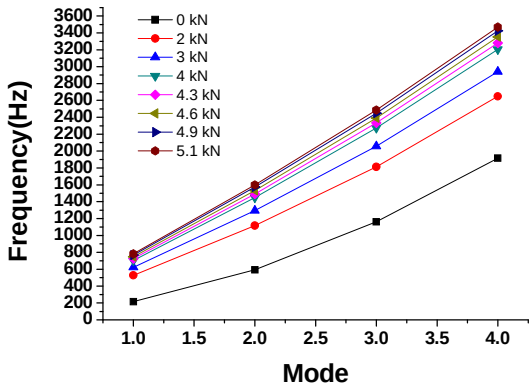
The natural frequency increased when tensile loads also increased depending on the stiffness of the beam [5]. Fig.6 shows the results obtained from FEM analysis and the results obtained from tensile testing.



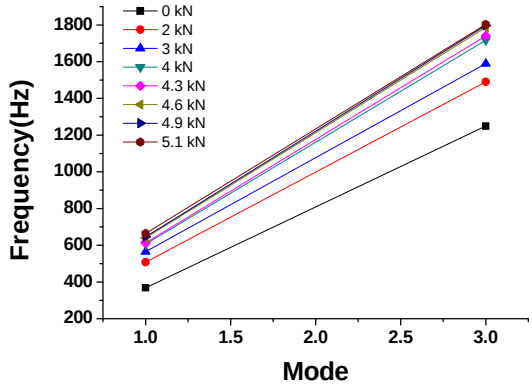
(a) Vibration mode Vs tensile load Obtained from FEM analysis



(b) Vibration mode Vs tensile load obtained from tensile testing



(C) Frequency Vs Mode obtained from FEM analysis



(d) Frequency Vs Mode obtained from tensile testing

Fig.6 The result of FEM analysis and tensile loading

If compared the FEM analysis with tensile testing, mode 1 and mode 2 measured shown in Fig.5 are mode 1 and mode 3 (see Fig.6). The reason that the mode 2 and mode 4 did not appear because tensile load was continue applied on specimen. So, it can be considered that the vibration of specimen was interfered. In Fig.6 shows that the results obtained from FEM analysis is similar to the results obtained from tensile testing.

4. Conclusion

(1) It can be known that the Natural frequency of vibration mode of carbon/carbon composite materials increased when tensile load was increasingly added.

(2) The reason that the vibration mode changed because the stiffness and the stress of materials also changed when the material was subjected to tensile load.

(3) During braking, the stiffness and tensile stress of carbon/carbon brake discs changed due to high temperature and tensile loading. Thus its frequency also changed.

Postscripts

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