INVESTIGATION ON VIBRATION ANALYSIS OF THE EFFECT OF FIBER BREAKS IN UNIDIRECTIONAL COMPOSITES

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Abstract: In this study, strength losses due to fiber breaks in unidirectional cantilever beam composites were investigated by vibration analysis. The fibers in a continuous Fiber Reinforced Plastic (FRP) composites have the largest percentage of FRP composites determined. Particularly the number of fibers in the continuous fiber used significantly affects the strength of the FRP composite produced. Because the continuous fiber used can be damaged during production or in composite manufacturing. For this reason, in this study, strength losses due to fiber breaks in FRP cantilever beam composites are investigated by mechanical vibration analysis. Finite element analysis (FEA) model is used for fiber breaks in composites. Damaged Fibers that transfer mechanical loads completely to the resin cause the loss of strength in FRP composites.

Keywords: Composite, FRP, Continuous Fiber, breaking, damage, vibration, FEA

Introduction

Composite materials have a wide range of applications because they have low density and high strength values. The areas of use of composite materials are frequently used in industrial and defense industries such as space, ship, commercial and passenger cars. Fiber reinforced composites (FRP) are important in composite materials. FRP composite materials are formed by combining the matrix and the fibers. The fibers carry the load and provide rigidity, while the matrix transmits the load to the fibers. Although these properties of composite materials are appreciated, they also tend to have defects that cause significant structural damage to the integrity of these materials. The mechanical properties of FRP materials depend on the type of fiber used. For this reason, any errors in the fiber can change the strength properties of the composite material. It is used as a sensor in carbon fiber composite materials having a fragile and conductive structure. Due to this feature, it has been observed that the electrical conductivity changes due to the fracture of the continuous carbon fibers in the composite structure (Chen & Liu, 2008; Wang & Chung, 1996; Wen, Xia, & Choy, 2011; Xia & Curtin, 2008). It has also been experimentally demonstrated that continuous carbon fibers are damaged by filament winding method by about 43% due to pretension applied to the fiber during production. (Genç & Akkus, 2017).

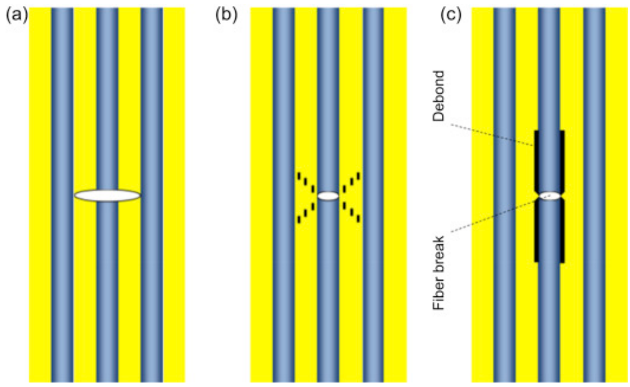

Figure 1. Fiber breaking in FRP composites

Fiber damage to FRP materials during production is important as the structure changes its mechanical properties. Because the fiber used to determine the mechanical properties of FRP materials has very great role. Especially in continuous fiber reinforced composites (CFRP), If some of the filaments in the fiber are breaking off during the production, the loads on the broken fiber are transferred to the resin (Fig.1). Thus, due to the resin having less mechanical properties, loss of strength occurs in that region of the composite. In this study, the effects of filaments breakage in the FRP composites were investigated by numerical analysis. Vibration modes have been studied on GFRP composites produced by one-way glass fiber by performing dynamic research in this study.

Materials and Methods

In FRP composite materials, it is important to reveal the loss of strength due to filaments breakage in fiber For this reason, 30x10x300 mm cantilever beam was used to investigate the effect of fiber breakage in FRP composite structures (Fig.2). In order to better understand the strength effect of fiber breakage, fibers are modeled unidirectionally in FRP composite cantilever beam. The mechanical properties of the cantilever beam due to fiber breakage will be investigated by FEA (Finite Element Analysis).

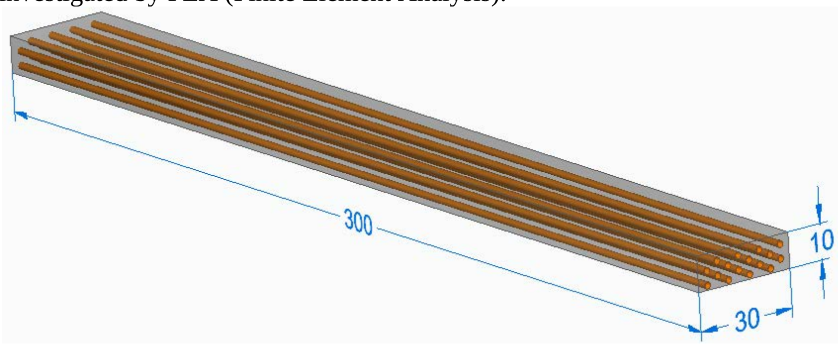

Figure 2. GFRP cantilever beam dimensions and 3D model of fiber orientation.

a) <u>Material Model</u>

In fiber reinforced composites, the mechanical properties of the composite vary depending on the type of fiber used, direction and mixture ratio because the fibers exhibit high strength and rigidity properties in the long axis direction. In such materials, the mechanical properties of the fiber direction (direction 1) are different from the mechanical values of the fiber direction 2 and 3 directions (Fig 3). For this reason, FRP composites are orthotropic material models (Huang, 2009; Sendikası, 09.01.2013).

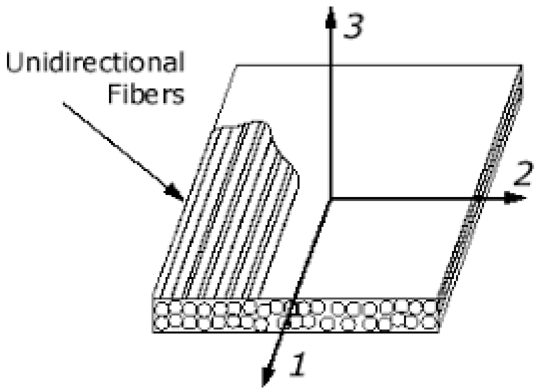

Figure 3. Orthotropic material model of FRP composites

In the composite material model, the cantilever beam are modeled epoxy and glass fiber reinforced, and the mechanical properties of the materials are given in Table 1. GFRP composites are modeled on a 60% glass fiber and 40% epoxy mixture ratio.

Table 1: Mechanical properties of materials used in composites.

Material	Properties	Symbol	Value
Glass Fiber	Elasticity Modulus	E_1^f	76 GPa
	Density	d^f	2,56 g/cm³
	Poisson's ratio	$\upsilon_{12}{}^f$	0,22
Epoxy Resin	Elasticity Modulus	E^m	4 GPa
	Density	d^m	1,3 g/cm³
	Poisson's ratio	υ^m	0,4

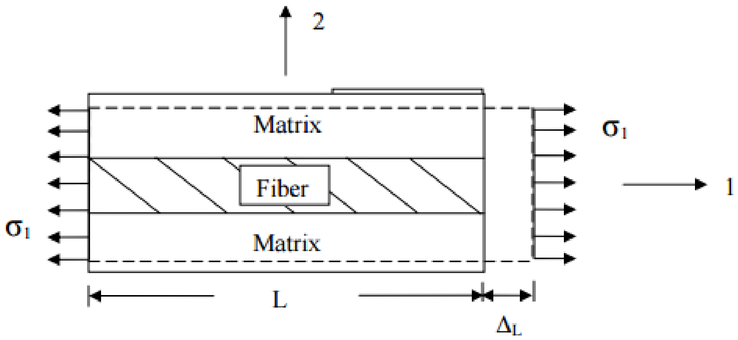

Figure 4. Unit volume element loaded in 1 direction (Facca, Kortschot, & Yan, 2006).

Composite mixture ratio was used in determining the mechanical properties of GFRP composite materials. Accordingly, as shown in Figure 4, it is necessary to determine the constants of the fiber-reinforced composite materials in the macrostructure. The mechanical properties of such materials vary depending on the rate of incorporation of the fiber and matrix in the unit cell. The mechanical properties are determined by Equation 2.1-2.3 using the fiber volume ratio (V^f) and matrix volume ratio (V^m) in the unit cell.

$$V^f + V^m = 1$$

$$E_1 = E^m V^m + E_1^f V^f$$

$$\upsilon_{12} = V^m \upsilon^m + V^f \upsilon^f$$

Material properties of the CFRP cantilever beam according to the glass fiber mixture ratio of 60% are as given in Table 2. This obtained data is valid if there is no break in the glass fibers in the cantilever beam.

Table 2. Material properties of undamaged GFRP composite

V^f	V^m	E_1^f GPa	E^m GPa	$\upsilon_{12}{}^f$	υ^m	d^f g/cm³	d^m g/cm³	E_1 GPa	υ_{12}	d g/cm³
0,6	0,4	76	4	0,22	0,4	2,56	1,3	47,2	0,292	2,056

b) FEA Analysis

The NX / Nastran Advanced Simulation program was used for FEA analysis of GFRP composite material. In the FEA model, CQUAD4 four node element type in 2D shell mesh were used. And this model consists of a total of 90 elements and 124 nodes. The results of the modal analysis of the GFRP cantilever beam are given in Table 3 and the mode shapes are shown in Figure 5.

Table 3. Vibration results of GFRP cantilever beam

Mod 1 (Hz)	**85,98**
Mod 2 (Hz)	**530,54**
Mod 3 (Hz)	**1451,47**
Mod 4 (Hz)	**2755,14**

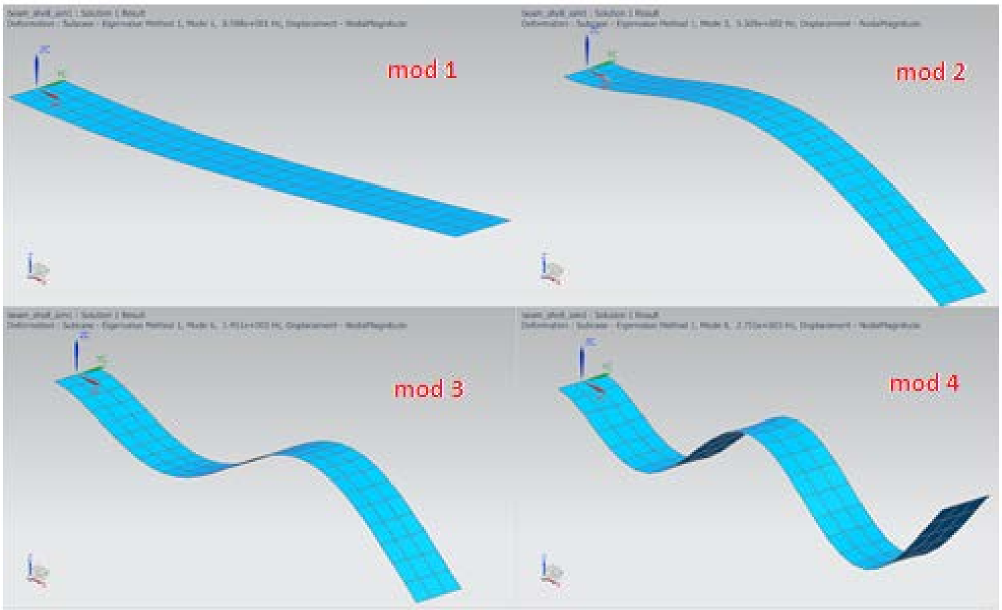

Figure 5. Mode shapes of GFRP cantilever beam

c) Vibration analysis based on Fiber Breaking

Since the fibers have a fragile structure, the fibers are of great importance in terms of the strength performance of the composite product. In FRP composites,It is accepted that the fibers do not carry the load in the regions where the fiber breakage occurs and all the load in that region carries the resin (Takehana, Akkus, Hidaka, & Kawahara, 1998). For this reason, damage to the fiber in GFRP composite materials affects the strength of the composite structure (Figure 6).

Figure 6. Model of the structure of damaged and undamaged fibers in FRP composites

Vibration analysis was performed to see the effect of fiber breaks in FEA analysis by modeling GFRP composites unidirectional. Vibration analyzes were performed to see the effect of fiber breaks on unidirectional modeled GFRP composites in FEA analysis. If the fibers in the composite beam are broken, the material properties of the beam change due to the variation of the mixture ratio in the cross section (Equation 2.1-2.3). Therefore, the modulus of elasticity of the composite varies depending on the mixture ratio as in Equation 2.2 (Figure 7). And also, the natural frequency values of the GFRP cantilever beam vibration analysis are given in Table 4 for four modes.

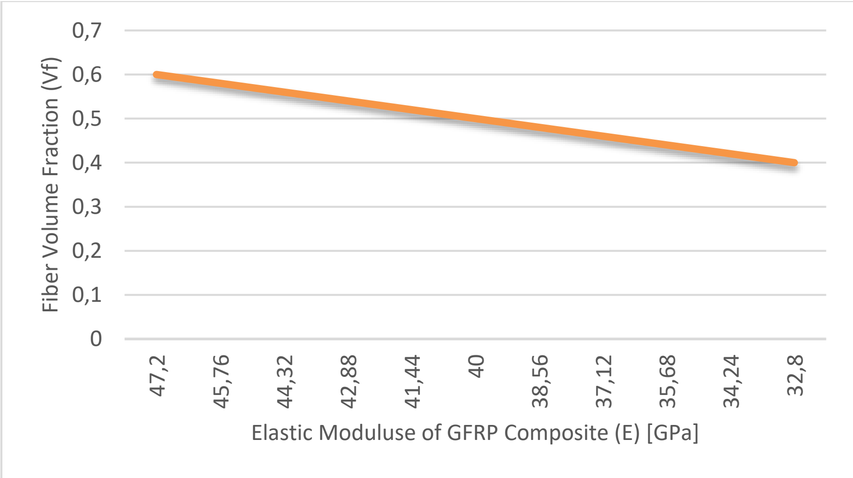

Figure 7. Change in elastic modulus of composite depending on fiber breakage.

Table 4. Vibration Analysis Results of Damaged GFRP Composite

Vf	Vm	E_1 GPa	Mod 1 Hz	Mod 2 Hz	Mod 3 Hz	Mod 4 Hz
0,6	0,4	47,2	85,99	538,93	1509,17	2957,44
0,54	0,46	42,88	81,96	513,68	1438,45	2818,85
0,5	0,5	40	79,16	496,13	1389,31	2722,54
0,44	0,56	35,68	74,76	468,57	1312,14	2571,33
0,4	0,6	32,8	71,68	449,26	1258,07	2465,37

Results and Discussion

The effect of fiber breaks on vibration analysis on GFRP cantilever beam was investigated. In the analysis, the damaged and undamaged states of the fibers were compared. In the study, it was assumed that the fibers were damaged according to the falling ratio of the fibers contained in the composite. In this case, vibration analysis was performed by changing the damage ratio of the glass fiber in the beam by the mixture ratio. This change was analyzed according to each mode value as shown in Fig 8. According to the result of approximately 30% reduction of fiber-to-fiber mixture ratio, while the elastic modulus of the composite decreases by 30%, the natural frequency values of the beam decrease by around 17%.

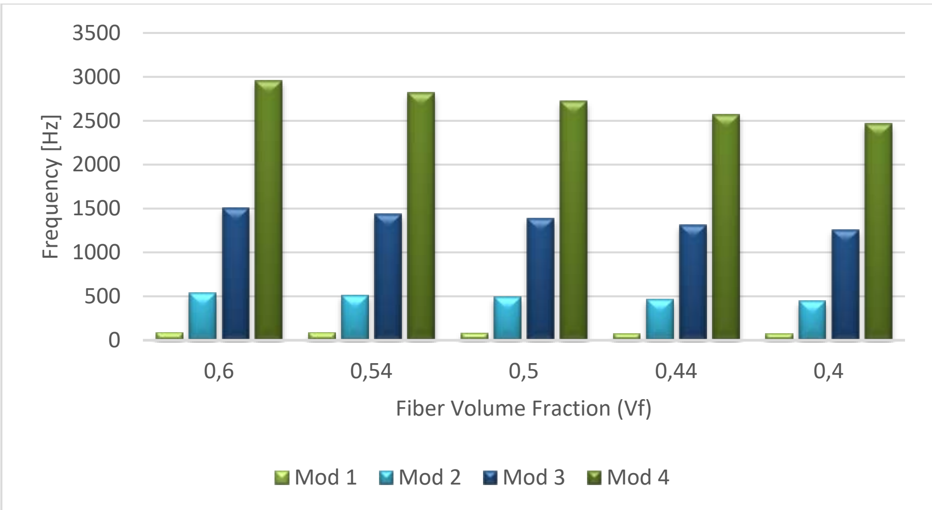

Figure 8. Vibration results due to fiber break in GFRP composites.

Conclusion

GFRP composite materials are widely used in today's industrial world. The strength performances of these materials vary depending on the type of fiber used and the amount of fiber. Due to the fracture of the fibers in the GFRP composites, the FEA analysis showed that the fibers exhibited loss of strength by not carrying the load in the regions where they existed. Because broken glass fibers transfer the load to the resin in the damaged area. For this reason, the breakage of fibers in fiber during production of FRP composites decreases the strength by affecting the produced product. This can lead to more serious problems for fiber types with more fragile structure such as carbon fiber.

Acknowledgements

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