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Theoretical analysis of fundamental natural frequency with different boundary conditions of isotropic hyper composite plate

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Abstract

This research presented isotropic hyper composite plates structures, which are made of (resin and fiber with powder as a reinforcement material). The basic item of this research is to improve the dynamical properties of the composite structure. This item has been verified by adding the powder as a reinforcement material. Square and rectangular hyper composite plates (AR=1 and 1.5) are made with different volume fractions for glass powder, resin and short fiber. Different boundary conditions are used (SSSS, CCSS, CCCC, CFFF, SSFF and CCFF) to support these plates. The dynamical properties of hyper composite models are calculated numerically with considering these different parameters. The results showed that the natural frequency increases by increasing the volume fraction of powder or short fiber with decreasing the resin. It can be concluded that the fundamental natural frequency in aspect ratio (AR=1) increased successively with the boundary conditions (CFFF, SSFF, SSSS, CCFF, CCSS, and CCCC) in ascending order, because the increasing in stiffness of the composite plate depends on the supporting conditions. And, for aspect ratio (AR=1.5), the fundamental natural frequency is increased successively with the boundary conditions (CCFF, CFFF, SSFF, SSSS, CCSS, and CCCC) in ascending order. Also the results showed that the fundamental natural frequency of aspect ratio 1 is larger than 1.5, because the ratio between stiffness to weight for AR=1 is larger than AR=1.5.

A comparison made between present numerical results and results presented by former published paper Abdulkareem et.al. [8] and theoretical results by Muhannad Al-Waily [9] for simply supported plate with aspect ratio (AR=1, a=b=25 cm and h=5 mm) and different volume fractions of resin, powder and short fiber and good agreement were the maximum error between numerical and experimental is results is about 5.73% (with 20% short reinforcement fiber, 30% powder reinforcement and 50% resin materialswhile the maximum error between numerical present results and theoretical results; Muhannad Al-Waily, [9] is about 12.86% (with 30% short reinforcement fiber, 20% powder reinforcement and 50% resin materials).

Keywords: Hyper composite plate; Fundamental natural frequency; Glass powder; Dynamical properties; Numerical study.

1. Introduction

The finite element method is a numerical method that can be used for the accurate solution of complex mechanical and structural vibration problems. In this method, the actual structure is replaced by several pieces or elements, each of which is assumed to behave as a continuous structural member called a finite element. The elements are assumed to be interconnected at certain points known as joints or nodes. Since it is very difficult to find the exact solution (such as the displacements) of the original structure under the specified load, a convenient approximate solution is assumed in each finite element.

The idea is that if the solution of the various elements is selected properly, they can be made to converge to the exact solution of the total structure as the element size is reduced. During the solution process, the equilibrium of forces at the joints and the compatibility of displacement between the elements are satisfied so that the entire structure (assemblage of elements) is made to behave as a single entry [1].

Composite materials have been used in structures for a long time. The ANSYS program allows modeling composite materials by using specialized elements called layered elements. Once the model is built using these elements, any structural analysis can be done (including nonlinearities be achieved such as large deflection and stress stiffening). No layered elements are currently available for thermal, magnetic, or electric field analyses [2]. There are many researchers studied the dynamical properties of plate as listed here some of their studies.

Sait Ozmen Eruslu and Metin Aydogdu, [3], studied vibration analysis of simply supported square laminated plates containing randomly and unidirectionally aligned short fibers. They obtained the modulus elasticity of composites used the Mori-Tanaka mean field method. They studied influences of the fiber aspect ratios, the plate span to thickness ratios, and the fiber volume fractions on the vibration manner. Their mode frequency results were compared with results of the finite element model and they observed that for increasing degree of orthotropy, the difference between the frequency parameters increases for increased aspect ratios and for greater aspect ratios, the natural frequency of short fibers draw close to those of continuous fibers .

Ioan curtu et.al, [4], presented a Paper studied the modal analysis of dynamical behavior of plates made from woven composite materials. They analysed the four type of composite with the differed of number of layers, thickness and pressure testing 15 samples for each type of composite. They obtained the results lead to natural frequency for each structure and modal shape using finite element method (FEM).

Luay S. Al-Ansari et.al, [5], studied a theoretical investigation for vibration analyses of hyper composite beam. Their hyper composite material was composed of long fiber and composite matrix that composed of resin, and short fibers. They developed a theory for the beam included the effect of transverse shear deformation and rotary inertia and studied influence of volume fractions and type of short, long reinforcement fibers and resin materials on the natural frequencies. Their analytical and numerical results showed the natural frequencies of the beam increased with the increasing of the strength of fiber and with the increase of volume ratios of the long fiber when used short fiber and long fiber of the same material.

Kanak Kalita and Abir Dutta, [6], studied different mode frequencies for free vibration of isotropic plates numerically considering several different boundary condition cases involving CCCC, SSSS supported uniform thickness and various aspect ratios (a/b= 0.4, 1.0, 1.5 and 2.0). They analyzed Square plate for various boundary conditions (SSSS, SSSC, SCSC, SCCC and CCCC) with various thickness ratio (a/h=5, 10, 20 and 50). Their results obtained were converted to nondimensional form for ease of comparison with other literatures.

From the previous studies that mentioned above, it is clear that the researchers concerned with the evaluation of the natural frequency of plates some of them are composite (combined from short fiber reinforcement, and resin) and some are hyper composite plates (combined from powder reinforcement, short fiber reinforcement, and resin), and studied effects of many influences as volume fractions type of short, long reinforcement fibers, aspect ratios, and several different boundary conditions on the natural frequency, where they utilized the analytical and numerical methods in their analysis. In this paper the numerical analysis is studied to evaluate the natural frequency of isotropic hyper composite materials (combined from powder reinforcement, short fiber reinforcement, and resin) with effects of different volume fractions of glass powder, aspect ratios, and six different boundary conditions.

2. Numerical study

Finite element method is used to evaluate the fundamental natural frequency, for isotropic composite plate for different volume fractions, six different boundary conditions, and two aspect ratios studied in this chapter. Element type, mesh generation and transient analyses are explicated minutely.

2.1 Element type

The ANSYS element collection covers various element types. The element type existing to model the plate is Shell 93 / 8 Node Structure Shell, which is mainly suitable for modeling curved shell and plate which is a shell of zero curvature. That element is of six degrees of freedom at each node: translation of the nodes x, y, and z coordinates and rotation about the nodes x axes, y axes, and z axes. The element contains plasticity, stress, and great deflection abilities.

The element geometry, node positions and coordinate's organization are presented in Figure 1. At the middle nodes element thickness considered as corresponds corner nodes average thickness. SHELL 93 element type suppositions and limitations are as following, [7]

1. Zero area element are not allowed. This occurs most often whenever the element are not numbered properly.
2. Zero thickness element or element tapering down to a zero thickness at any corner are not allowed.
3. The applied transverse thermal gradient is assumed to vary linearly through the thickness.
4. Shear deflections are included in this element.
5. The out-of-plane (normal) stress for this element varies linearly through the thickness.

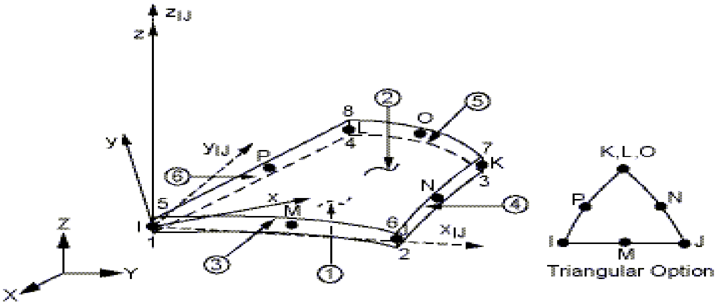


Figure 1. Used Element Type (Shell 93 / 8 Node), [7].

2.2 Mesh selection

The selection of mesh is the most significant attribute in the finite element considerations. Many trials in this study are done to select the proper mesh and achieve reasonable results, since the increased number of elements will leads to the correct results, but, in many cases the increased number leads to an incorrect results.

The composite plate are divided to (144 - 36864 elements) for aspect ratio (AR=1) and (216 - 8288 elements) for aspect ratio (AR=1.5) as presented in Table 1 and Figure 2.

It is observed from the results that the fundamental natural frequencies of the composite plates achieve the stable value at second trial. The chosen number of element was third trial at 2304 elements for aspect ratio (AR=1), and 3552 elements for aspect ratio (AR=1.5).

Table 1. The mesh generation of the composite plate for AR=1.

Number of Trial	Length *width Divisions	Number of elements	Natural Frequency (Hz)
1	12*12	144	458.3
2	24*24	57	458.26
3	48*48	2304	458.248
4	96*96	9216	458.249
5	144*144	20736	458.249
6	192*192	36864	458.249

2.3 The boundary conditions

The boundary conditions are another significant attribute that define the circumferential effects influenced on the structures. In the current study six different boundary conditions are used (SSSS, SSFF, CCSS, CCFF, CFFF, and CCCC) to support the composite plate. Figure 3 shows the plates boundary conditions where the edges with UX, UY, UZ, ROTX, ROTY and ROTZ not equal to zero needed to be evaluated. ROTX, ROTY and ROTZ are presented by θx, θy, and θz.

Many attempts to select the value of force which is applied have been taken place. The composite plate is solved numerically in order to extract the value of maximum von Mises stress induced in the plate corresponding to the applied force. The lateral force is applied, where a small value of lateral force gives a reasonable value of induced stress and vice versa. Therefore, a lateral force of (10 N) is applied to the canter of plate for all boundary conditions and two aspect ratios (AR=1, 1.5) as shown in Figure 4.

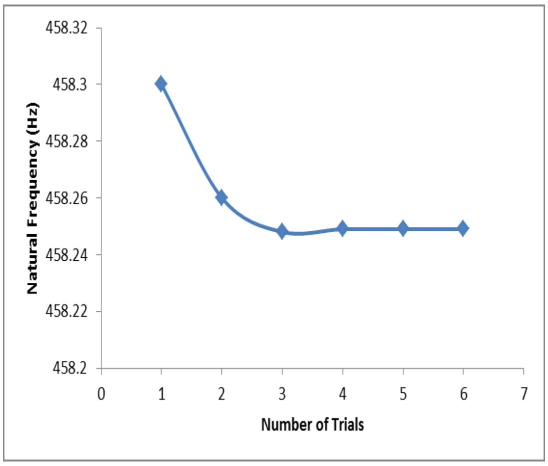


Figure 2. The relation between fundamental natural frequencies of the composite plate with the number of trials for AR=1.

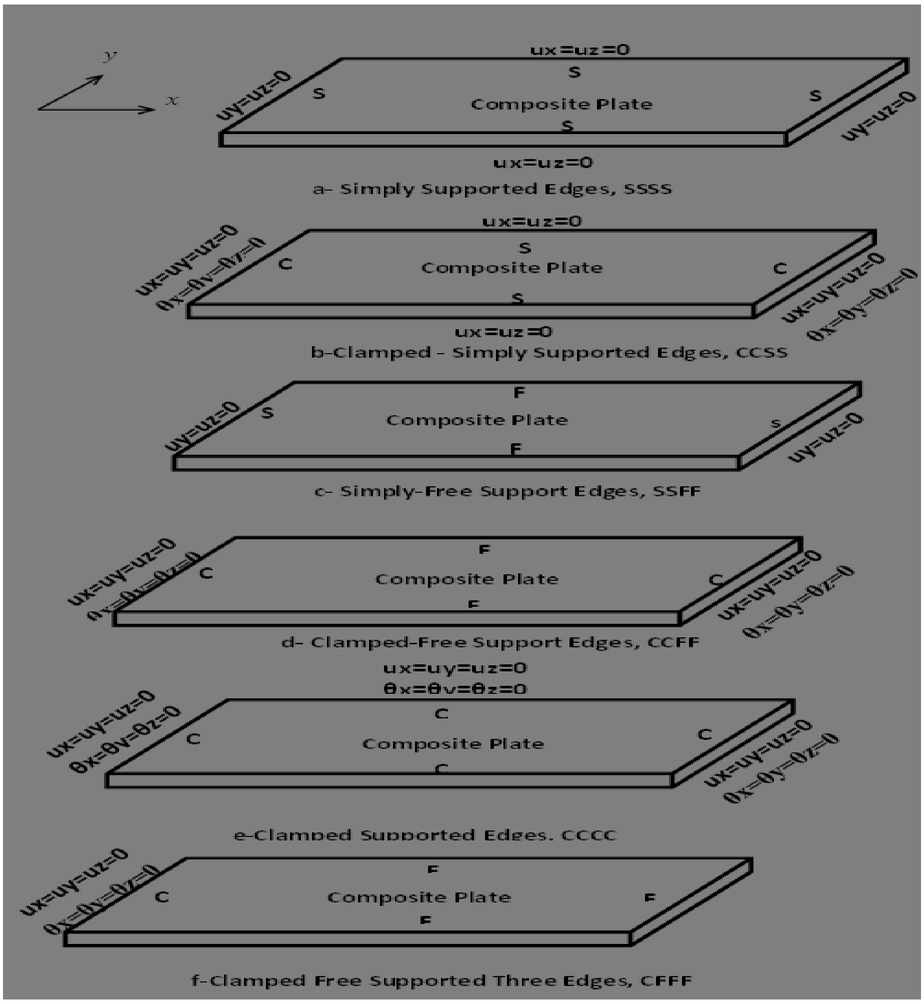
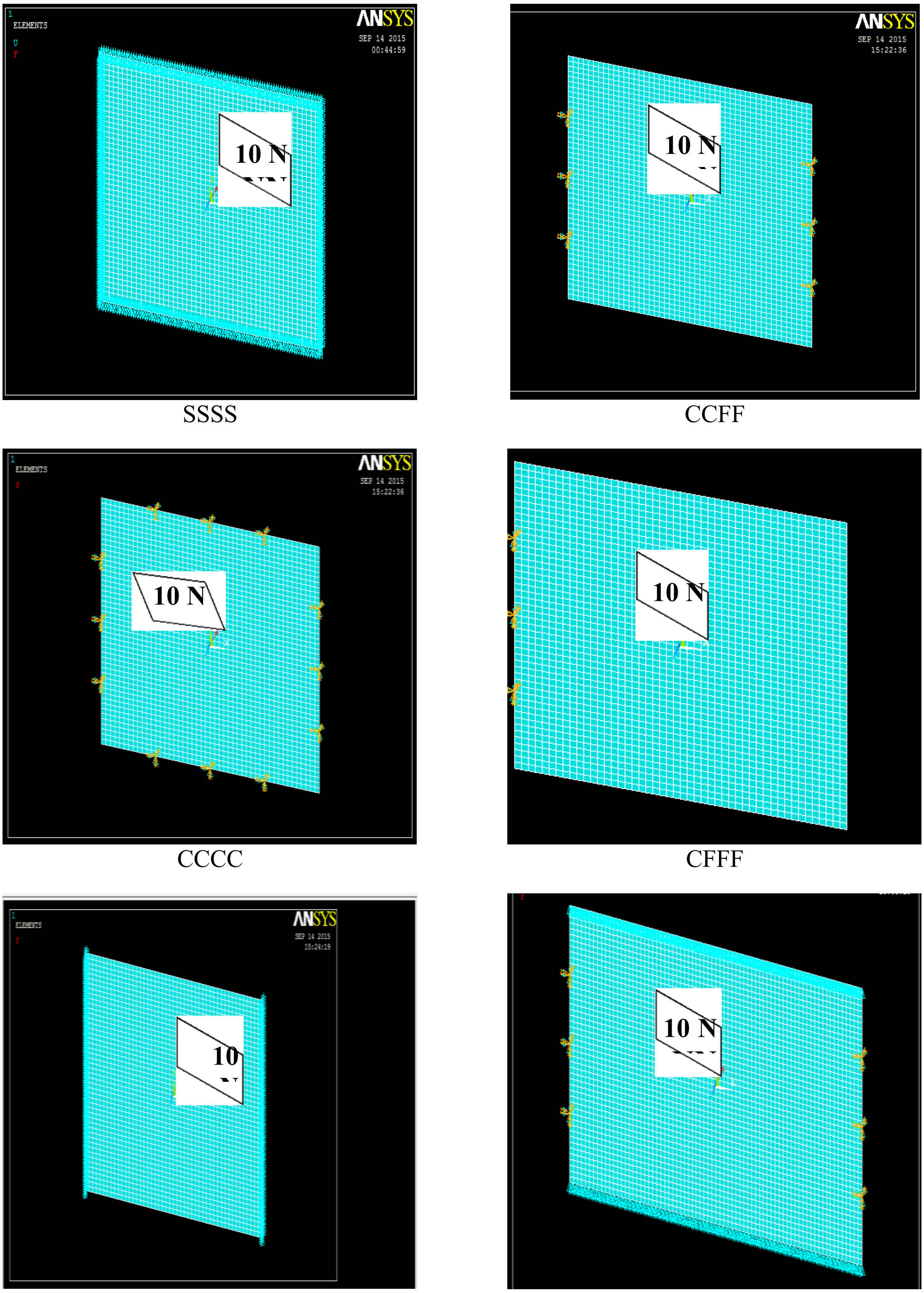


Figure 3. Composite plate boundary conditions.



SSSS CCFF

CCCC CFFF

SSFF CCSS

Figure 4. Composite plate loaded at all boundary conditions for AR=1.

3. Results and discussions

The numerical vibration results evaluated the fundamental natural frequency of isotropic hyper composite plates for different aspect ratios (AR=1, 1.5), and six different boundary conditions (SSSS, SSFF, CFFF, CCSS, CCFF, and CCCC), including ANSYS program.

The theoretical properties of isotropic hyper composite materials combined of short glass fiber, glass powder as reinforcements, and polyester resin matrix for different volume fractions are shown in Table 2, and the dimensions and boundary conditions of composite plates that studied are shown in Table 3.

Table 2. Theoretical mechanical properties of composite plates for different volume fractions of glass powder.

$\forall_{sf}\%$	$\forall_{p}\%$	$\forall_{r}\%$	E (Gpa)	G (Gpa)	ν	ρ (kg/m^3)
30	0	70	14.004	5.006	0.398	1440
20	10		12.057	4.365	0.3811	1480
10	20		9.926	3.647	0.3608	1520
40	0	60	17.867	6.381	0.3998	1520
30	10		16.107	5.814	0.3851	1560
20	20		14.075	5.134	0.3706	1600
10	30		11.9357	4.407	0.354	1640
40	10	50	20.6851	7.469	0.3843	1640
30	20		18.785	6.843	0.3725	1680
20	30		16.741	6.151	0.36	1720
10	40		14.6716	5.441	0.348	1760

Table 3. Dimensions and boundary conditions of isotropic hyper composite plate studied.

Length, a (cm)	25
Width, b (cm)	25, 37.5
AR (b/a)	1, 1.5
Thickness, h(mm)	5
Boundary Conditions	SSSS, CCSS, SSFF,CCFF, CCCC, CFFF

3.1 Verification case study

The comparison of fundamental natural Frequency for isotropic hyper composite plates studied between numerical present results and experimental results presented by former published paper Abdulkareem et al. [8], and theoretical results by Muhannad Al-Waily [9], for simply supported plate with aspect ratio (AR=1, a=b=25 cm and h=5 mm) and different volume fractions of resin, powder and short fiber, Table 4, and Figure 5 showed that. (from Table 4) the maximum error between numerical present results and experimental results presented by former published paper Abdulkareem et al. [8] is about 5.73% (with 20% short reinforcement fiber, 30% powder reinforcement and 50% resin materials) and the minimum error about 3.12% (with 30% short reinforcement fiber, 10% powder reinforcement and 60% resin materials). While the maximum error between numerical present results and theoretical results; Muhannad Al-Waily [9] is about 12.86% (with 30% short reinforcement fiber, 20% powder reinforcement and 50% resin materials) and the minimum error is about 11.17% (with 20% short reinforcement fiber, 20% powder reinforcement and 60% resin materials.

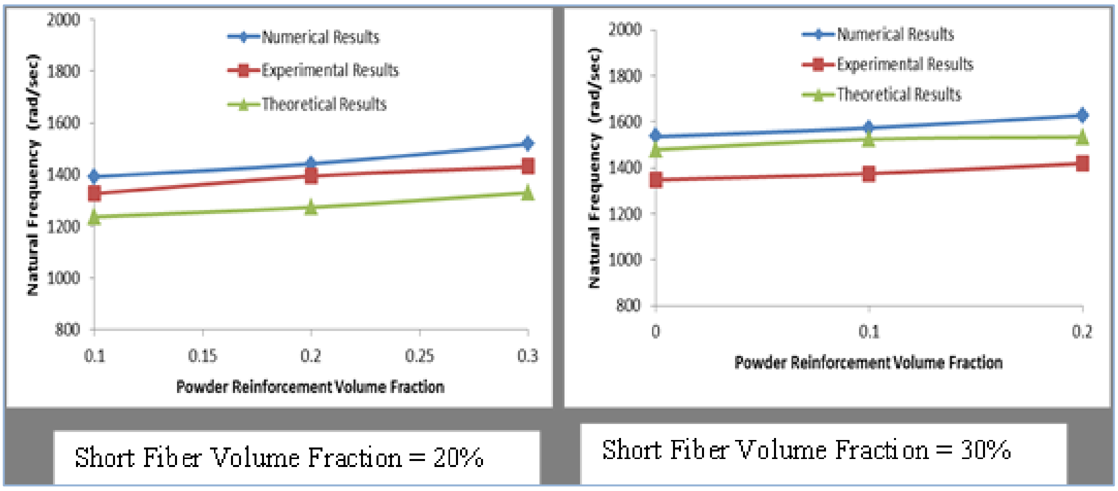
3.2 Parameters effect

Figure 6 shows the relationship between volume fraction of reinforcement powder and the fundamental natural frequency of isotropic composite plates of six boundary conditions of plate (SSSS, CCSS, CCCC, CCFF, CFFF, and SSFF) for aspect ratios (AR=1, 1.5).

These figures indicate that the fundamental natural frequency increased with the volume fraction of powder increasing, because the increase in the stiffness led to that the modulus of elasticity of composite plates increased.

Table 4. Experimental and theoretical (Muhannad Al-Waily, [9]) fundamental natural frequency results, of (SSSS) plates and (AR=1).

$\forall_{sf}\%$	$\forall_{p}\%$	$\forall_{r}\%$	ω (rad/sec) Numerically	ω (rad/sec) Experimentally	ω (rad/sec) Theoretically	Error % Num Exp	Error % Num th
30	0	70	1535.92	1478.7	1347.014	3.7	12.29
20	10		1392.33	1327.05	1236.749	4.6	11.17
30	10	60	1572.99	1523.84	1374.748	3.12	12.6
20	20		1442.43	1394.7	1274.106	3.3	11.66
30	20	50	1627.59	1534.3	1418.263	5.7	12.86
20	30		1518.52	1431.4	1329.897	5.73	12.42



Short Fiber Volume Fraction = 20%

Short Fiber Volume Fraction = 30%

Figure 5. Comparison between experimental and theoretical (Muhannad Al-Waily, [9]) results of natural frequency.

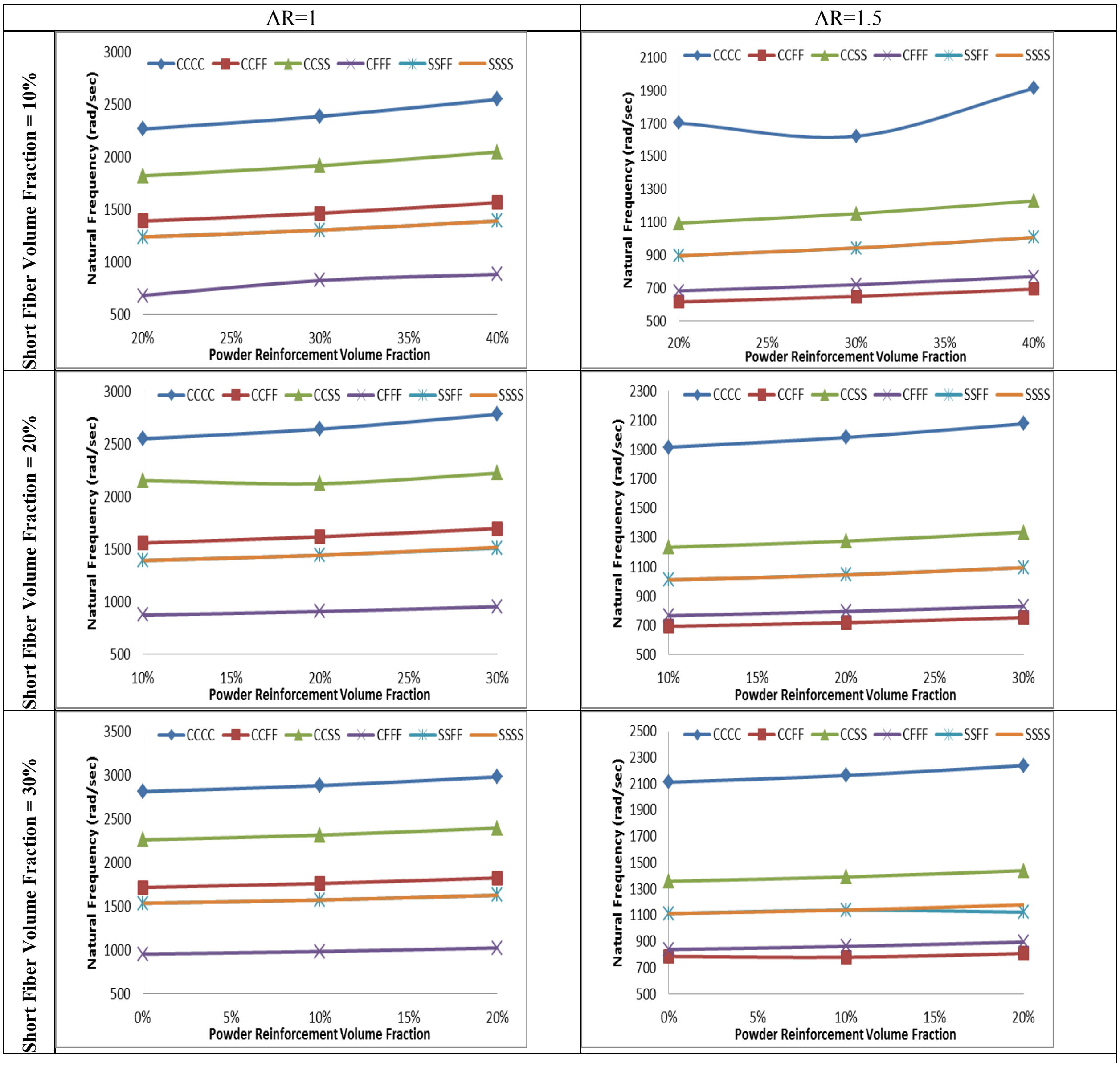


Figure 6. Numerical results for 10, 20, and 30% volume fractions of short fiber with different boundary conditions for AR= 1, 1.5.

Figure 7 show the relationship between volume fraction of short reinforcement fiber and the fundamental natural frequency of isotropic composite plate of different boundary conditions of plate (SSSS, CCSS, CCCC, CCFF, CFFF, and SSFF) for aspect ratios (AR=1, 1.5).
Figure 8 demonstrate the relationship between the fundamental natural frequency and different volume fractions of powder reinforcement and short fiber reinforcement, respectively with two aspect ratios (AR=1, 1.5) for 30%, 40%, and 50% total reinforcements volume fractions for simply supported (SSSS) boundary condition experimentally.

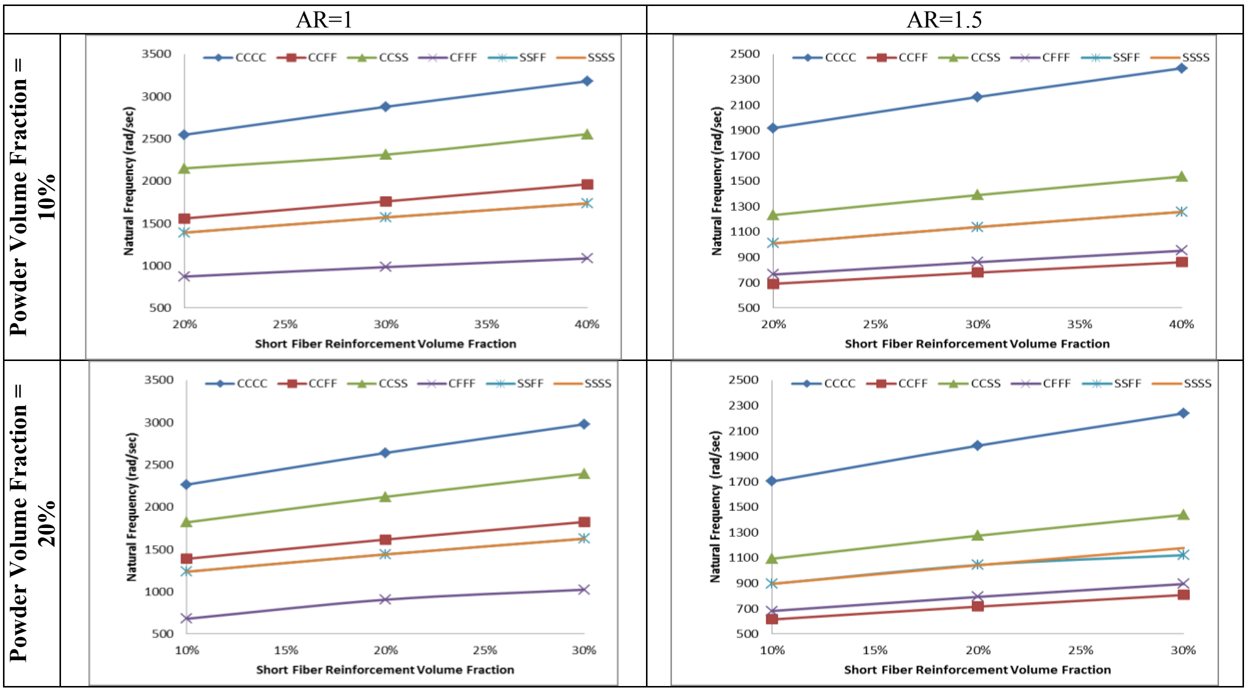


Figure 7. Numerical results for 10, and 20% volume fractions of glass powder with different boundary conditions for AR= 1, 1.5

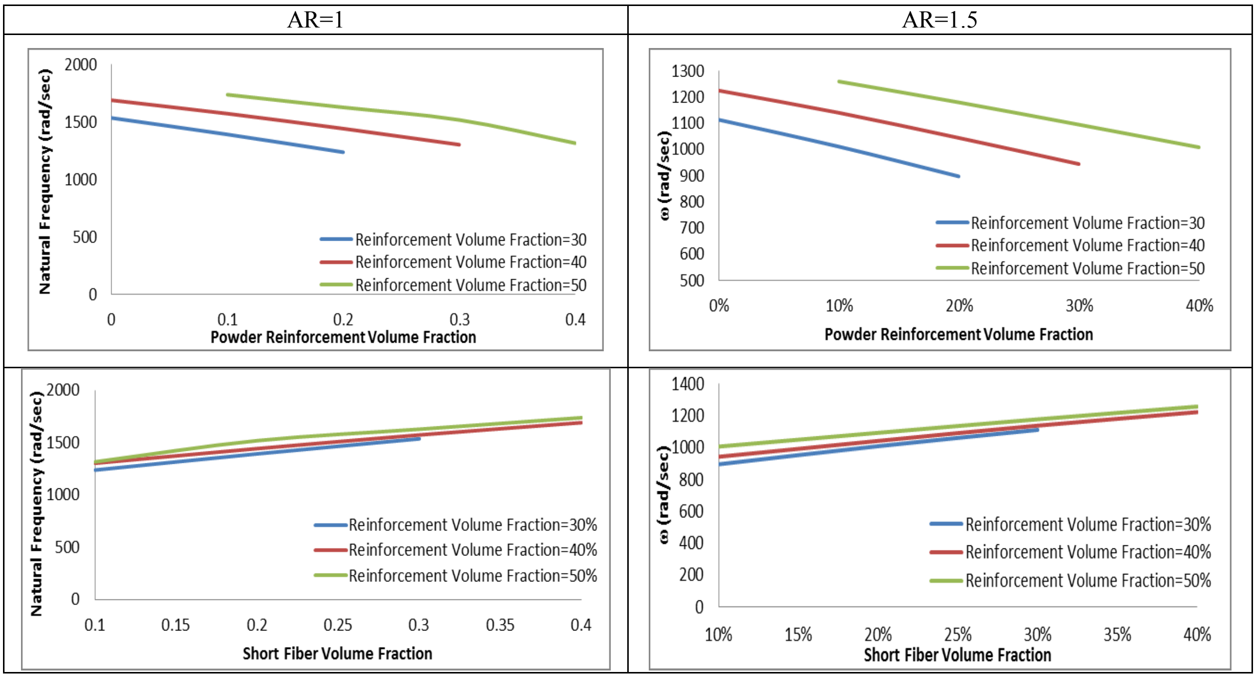


Figure 8. Experimental results for different volume fractions of powder and short fiber for AR=1, 1.5 for SSSS boundary condition.

Figure 9 shows the relationship between the fundamental natural frequency and different volume fractions of powder reinforcement and short fiber reinforcement, respectively with two aspect ratios (AR=1, 1.5) for 30%, 40%, and 50% total reinforcements volume fractions for simply free supported (SSFF) boundary condition experimentally.

Figure 10 shows the relationship between the fundamental natural frequency and different volume fractions of powder reinforcement and short fiber reinforcement, respectively with two aspect ratios (AR=1, 1.5) for 30%, 40%, and 50% total reinforcements volume fractions for clamped simply supported (CCSS) boundary condition experimentally.

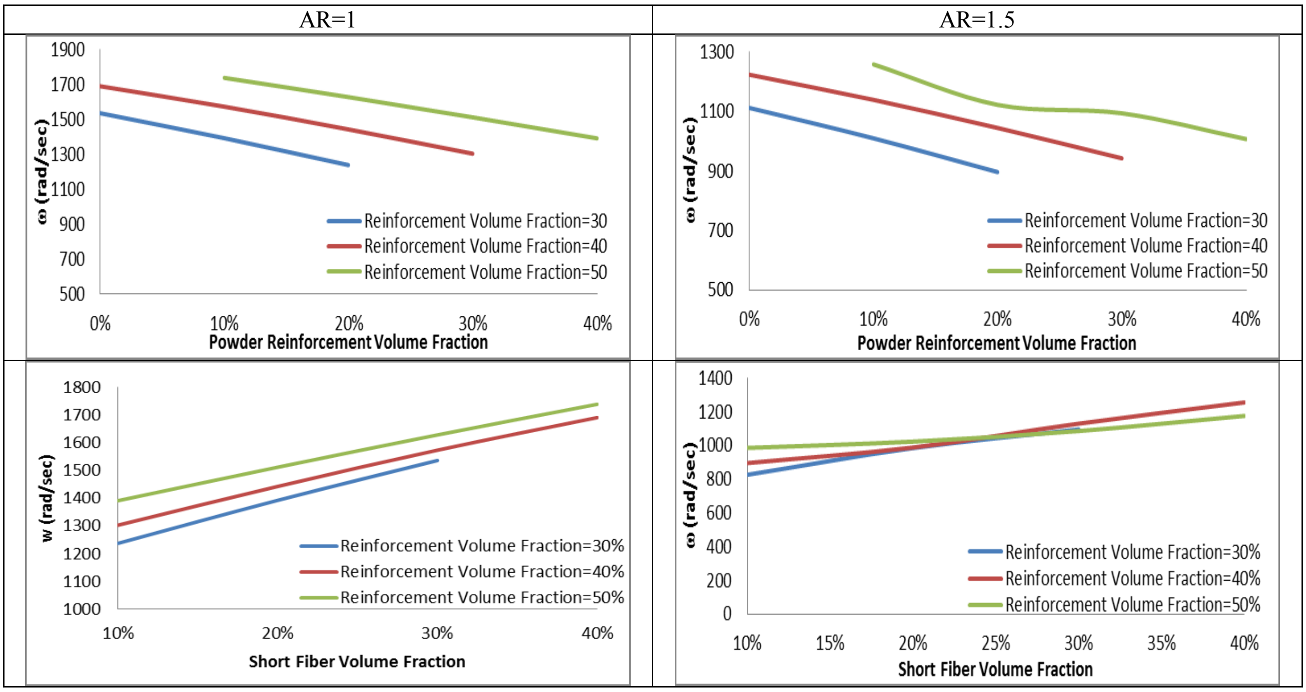


Figure 9. Experimental results for different volume fractions of powder and short fiber for AR=1, 1.5 for SSFF boundary condition

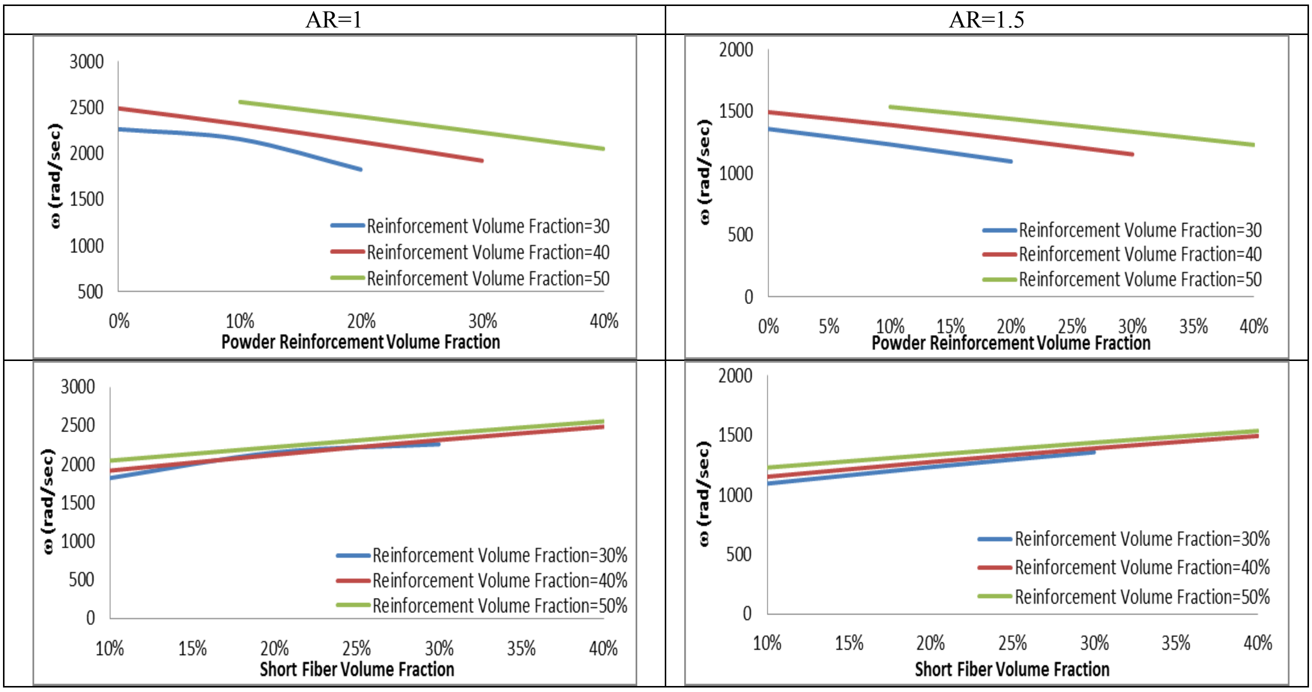


Figure 10. Experimental results for different volume fractions of powder and short fiber for AR=1, 1.5 for CCSS boundary condition.

Figure 11 depicts the relationship between the fundamental natural frequency and different volume fractions of powder reinforcement and short fiber reinforcement, respectively with two aspect ratios (AR=1, 1.5) for 30%, 40%, and 50% total reinforcements volume fractions for clamped free supported (CCFF) boundary condition experimentally.

Figure 12 reveals the relationship between the fundamental natural frequency and different volume fractions of powder reinforcement and short fiber reinforcement, respectively with two aspect ratios (AR=1, 1.5) for 30%, 40%, and 50% total reinforcements volume fractions for clamped free supported (CFFF) boundary condition experimentally.

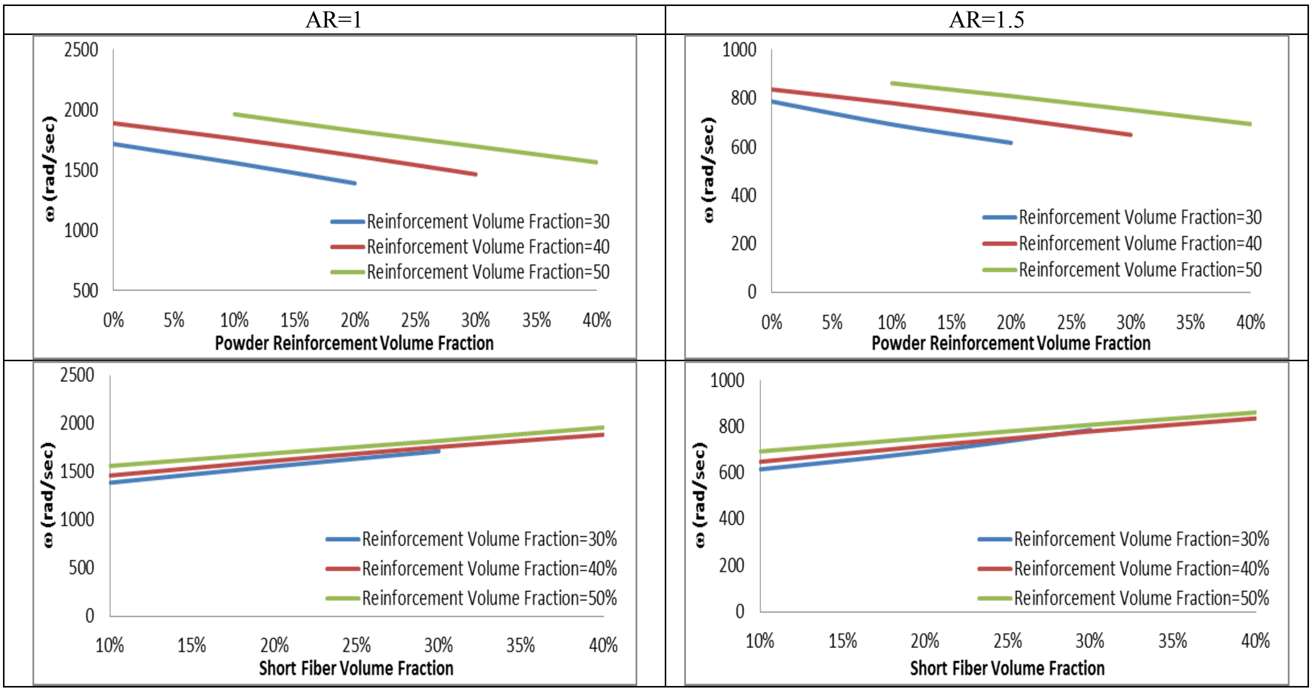


Figure 11. Experimental results for different volume fractions of powder and short fiber for AR=1, 1.5 for CCFF boundary condition

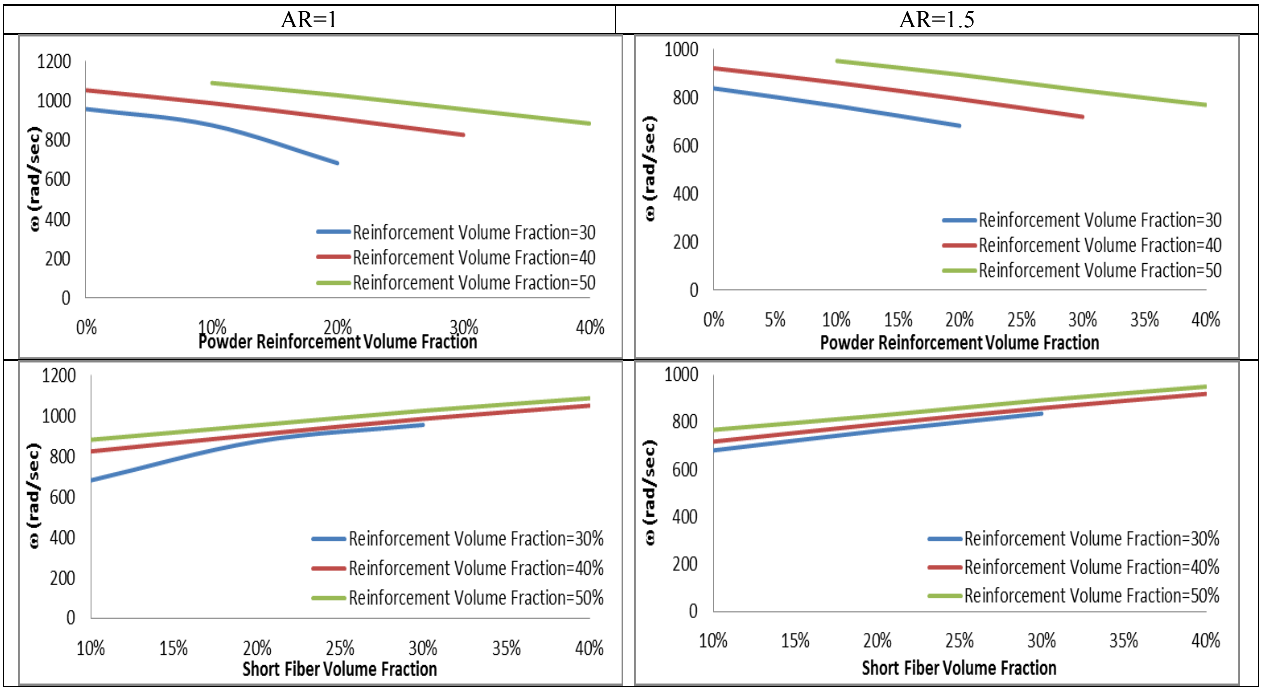


Figure 12. Experimental results for different volume fractions of powder and short fiber for AR=1, 1.5 for CFFF boundary condition.

Figure 13 shows the relationship between the fundamental natural frequency and different volume fractions of powder reinforcement and short fiber reinforcement, respectively with two aspect ratios (AR=1, 1.5) for 30%, 40%, and 50% total reinforcements volume fractions for clamped supported (CCCC) boundary condition experimentally.

Figures 8 to 13 indicate that the fundamental natural frequency decreased when the ratio of powder reinforcement to total reinforcement increased but it increased when the ratio of short fiber reinforcement to total reinforcement increased.

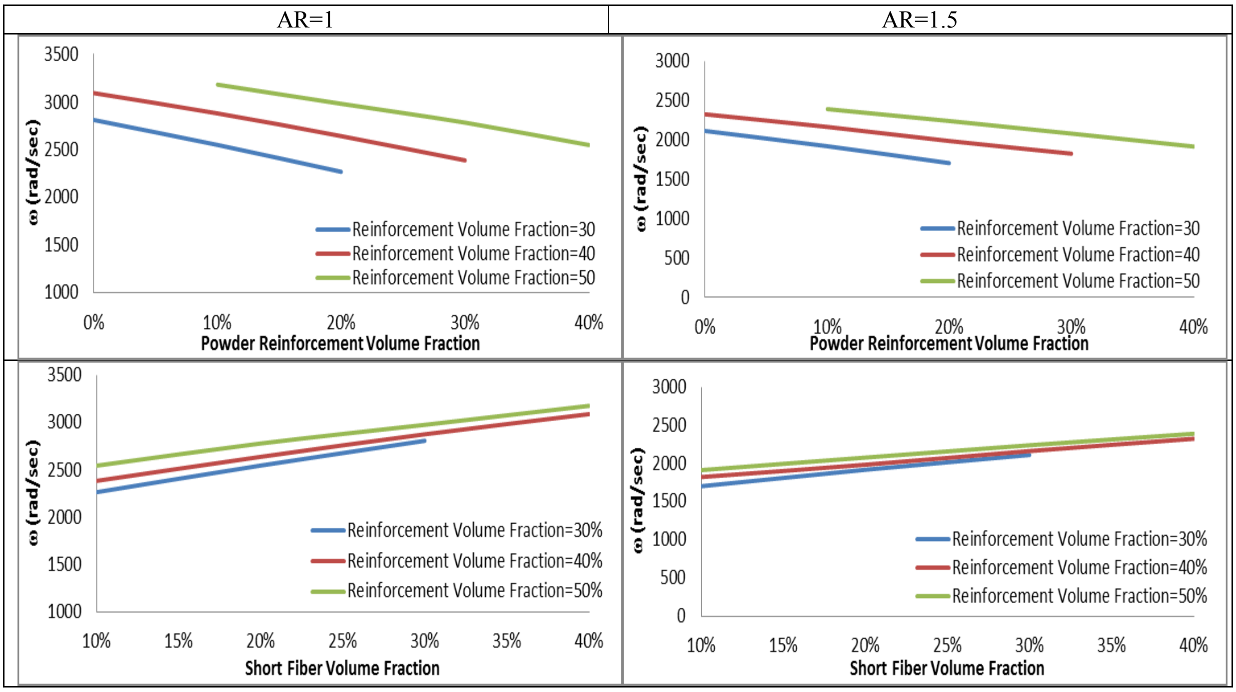


Figure 13. Experimental results for different volume fractions of powder and short fiber for AR=1, 1.5 for CCCC boundary condition.

4. Conclusion

1. A comparison between numerical present results and experimental results is about 5.73% and the maximum error between numerical present results and theoretical results; (Muhannad Al-Waily, 2013) is about 12.86%.
2. The fundamental natural frequency of hyper composite plate was increased with the increase of short fiber volume fraction ($\forall_{sf}\%$) and powder volume fraction ($\forall_{p}\%$).
3. The Clamped-Free support three edges (CFFF) boundary condition showed the lowest values for aspect ratio (AR=1) and Clamped-Free supported (CCFF) for aspect ratio (AR=1.5), the Clamped-supported along all edges (CCCC) boundary condition showed the highest values of the natural frequency for both aspect ratios.
4. The fundamental natural frequency decreased when the ratio of powder reinforcement to total reinforcement increased and the fundamental natural frequency increased when the ratio of short fiber reinforcement to total reinforcement increased.

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