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Dynamical Behavior of Hybrid Kevlar/Carbon Pipe Reinforced Epoxy Conveying Water

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Abstract

The research included a study of the effect of reinforcement with non-continuous hybrid fibers consisting of Kevlar fibers and carbon fibers with epoxy resin on the natural frequency of pipes conveying water, as well as its effect on the maximum flow speed of water through the pipes, known as the critical speed, for different boundary conditions represented by clamped–clamped and pinned–pinned. The epoxy resin was reinforced by Kevlar fibers compared with the model reinforced by carbon fibers at the same volumetric ratios. The length of the short fiber depends on the ratio between length of short fiber and critical length of short fiber as (L/Lc = 1, 2, ….. and 20). To obtain a hybrid composite material, both carbon fibers and Kevlar fibers were combined with the matrix material at different proportions. In the hybrid model, the structure has high stiffness in withstanding tensile stress which obtained from carbon fibers in addition to that presence of kevlar fibers in the structure design gives great toughness in resisting external impacts. The calculations were carried out using the mathematical program (MATLAB) according to Rayleigh's approximate method. It was noted that the natural frequency of the system and the critical speed of flow are greater in the carbon fiber model than in the Kevlar and hybrid fiber models. The consequence of altering the thickness and diameter of the models on the dynamic behavior of one-meter-long pipe was investigated. The study revealed that the natural frequency and critical speed increase with increasing the thickness of the pipe wall and its diameter, according to the type of fixation. The percentage of improvement in the natural frequency for pipe with different cross sections ranges from 4.9% , 9%, 12.6% to 15.8% which rises with increasing in the volume fraction of the carbon fibers in the hybrid composite materials for different fixations. Regarding the percentage of enhancement in critical velocity which ranges from 4.9% , 9.4%, 13.2% to 16.6 % as it improves with increase in the percentage of the volume fraction of carbon fibers in the hybrid pipe. A theoretical comparison was made with research that used a model with different dimensions. The results were at an acceptable difference ratio.

Key Words: Epoxy, Fibers Carbon, Fibers Kevlar, Fluid Conveying Pipe, Hybrid Fibers, Length Ratio.

List of Symbols

A_{cp} – Cross section area of hybrid pipe $[m^2]$;
A_w – Cross section area of water $[m^2]$;
E_c – Modulus elasticity of Carbon fibers $[N/m^2]$;

E_{cp} – Modulus elasticity of hybrid fibers [N/m^2];
E_{ep} – Modulus elasticity of epoxy resin [N/m^2];
E_k – Modulus elasticity of Kevlar fibers [N/m^2];
f_1 – Volume fraction of Kevlar fibers;
f_2 – Volume fraction of Carbon fibers;
f – Volume fraction of hybrid fibers;
L – Short fiber length;
L_c – Critical length of fibers;
L_p – Length of pipe [m];
I_{cp} – Second moment of area of composite pipe [m^4];
m_w – Mass of fluid per unit length [kg/m];
m_p – Mass of pipe per unit length [kg/m];
t – Thickness of pipe [mm];
R_i – Inner radius of composite pipe, [cm)];
R_o – Outer radius of composite pipe, [cm];
V_c–Critical velocity of fluid flows in the pipe [m/sec];
V_{cc}–Critical velocity of fluid flows in the clamped – clamped pipe [m/sec];
V_{pp}– Critical velocity of fluid flows in the pinned - pinned pipe [m/sec];
ρ_c – Mass density of Carbon fibers [kg/m^3];
ρ_{cp} – Mass density of hybrid composite pipe [kg/m^3];
ρ_{ep} – Mass density of epoxy resin [kg/m^3];
ρ_f – Mass density of fibers [kg/m^3];
ρ_k – Mass density of Kevlar fibers [kg/m^3];
ω_{pp}–Natural frequency of pinned-pinned pipe [rad/sec];
ω_{cc}–Natural frequency of clamped – clamped pipe [rad/sec)].

1. Introduction

Composite materials can be considered an ideal alternative to other materials (ceramics, polymers, and metals**).** The purpose of composite materials is obtaining industrial materials with engineering applications and high-quality characteristics. Composite materials have been created by mixing two or more materials, such as fibers or nano- or particulate materials with light weights and excellent mechanical properties. Huge quantities of composite materials estimated at tons can be produced from natural materials as well as from industrial materials that can be used in many engineering applications such as transportation buildings, furniture, railway vehicles, and as sources of alternative energy. The applications of carbon fibers pipes is in the automotive industry as racing cars, high-end sports cars, construction industry as bridges and wind turbines. They are use in boats and other watercraft, where resistance to corrosion and their strength. They are also used in the production of offshore oil rigs and other marine structures. Because of their extraordinary and distinctive qualities, these fibers can be used in a wide range of applications. The Kevlar fibers are used in airplane components, boat hulls, sports products, armor resistant to bullets and used in airplanes to reduce fuel consumption.

A practical study was conducted on six samples of composite materials containing different percentages of hybrid carbon fibers with Kevlar fibers to test the mechanical properties of the composite materials, which were represented by testing flexural strength and impact strength in addition to the modulus of elasticity. The researcher noted that when the volumetric percentage of Kevlar fibers increased from 20% to 60%, it contributes to increasing the modulus of elasticity and flexural strength more than samples containing carbon fibers only. Kevlar fibers also cause an increase in the impact strength of composite materials [1]. The ANSYS program is used to analyze the vibration generated in a drive shaft made of a composite material consisting of carbon fibers with epoxy resin, according to various factors such as static torque, adhesion points, critical speed, and fiber rotation. The results showed that the drive shaft weight reduced by about 72% when compared to the steel drive shaft [2]. Focused on the dynamic behavior of cantilever pipes composed of two pieces made of hybrid composite materials.The first group included a hybrid material of aluminum and steel, while the second model was made from epoxy with aluminum. The study showed that the hybrid pipes have more complex dynamic behavior at high flow speeds when compared to normal pipes [3]. A theoretical study was conducted on two different models of composite pipes made of polyester reinforced with glass fibers in the first model and Kevlar fibers reinforced with the base material in the second model at a different length ratio for the fibers, ranging from short fibers to long continuous, at different boundary conditions. The study showed that pipes reinforced with continuous Kevlar fibers have a natural frequency and critical speed greater than that of pipes reinforced with glass fibers. The pipe is clamped from both sides has a higher frequency in the case of cantilever pipe [4]. Conducted practical tests to predict the mechanical properties of hybrid composite materials containing epoxy resin reinforced with glass fibers and jute fibers. The tests included shear, tensile, bending, and impact strength. The research showed that the hybrid composite materials possess better mechanical properties than composite materials made of glass fibers or jute fibers separately [5]. Samples were prepared from composite materials based on epoxy resin that were reinforced with multi-walled carbon nanomaterials and alumina particles at different percentages ranging from 0.25% to 1%. The results revealed that the mechanical properties become less resistant to tension and impact strength when nanoparticles are added. On the other hand, there is an improvement in vibration behavior due to the increase in stiffness [6]. The mechanical properties of the hybrid composite material are from polyester as a base material, reinforced with natural jute fibers and glass fibers at the lowest cost, corresponding to a good improvement in the mechanical properties at a weight percentage of about 18%. Tensile tests, impact, and flexural tests were performed, as well as the natural frequency of the samples was studied during vibration analysis of the samples [7]. Focused on the problems of vibration generated in pipelines made of composite materials. It relied on the viscosity properties of the materials composing the pipelines, in addition to the effect of internal pressure and axial force of the lumped mass using the Galerkin method. The study concluded that the critical flow rate decreases with increasing viscosity and internal pressure, while natural frequency increases when the lumped mass is far from the center of the pipelines [8].

Investigated the mechanical properties by using waste natural as walnut peels and sawdust to strengthen polyester in mass fractions (10, 15, and 20)%, experimental tests were conducted for static compression, where the modulus of elasticity of the matrix increased when adding walnut peels more than adding sawdust [9]. The mechanical properties of a model of a composite material consisting of epoxy resin reinforced with glass fibers and carbon fibers were studied. Alumina particles (Al_2O_3) were added to conduct a tensile, shock, bending test, in addition to a free vibration test. The results showed an improvement in the mechanical properties

Vol. 33, No.2. \ 2025 ISSN: 2616 - 9916

after adding alumina particles [10]. Studied the effect of changing the shaft diameter on the dynamic response of the system with different boundary conditions. The composite material consists of polyester resin reinforced with glass fibers at a volume fraction of 40% for three samples with different diameters. The factors affecting the critical speed were also studied, as it depends on the boundary condition [11]. A practical study to predict the values of the non-dimensional natural frequency of composite pipes made of epoxy resin as a base material reinforced with carbon fiber to obtain low vibration with a low rate of corrosion and at different boundary conditions. The effect of the speed of water flow inside the pipe and the extent of its effect on the dynamic behavior of the system was also studied. Theoretical comparison with practical results and the effect of internal damping on the dynamic behavior of pipes was studied [12].

An improvement was made on a flax fiber composite material with a polymeric basis and it was transformed into a hybrid composite material by adding carbon fibers to it, which helped improve the mechanical properties of the hybrid composite material. During the tensile test, the layers were arranged so that the carbon fibers were the inner layers while the linen was the outer layers [13]. A practical study was conducted to predict the mechanical behavior of a number of samples manufactured from hybrid composite materials represented by short glass fibers with woven glass fibers at different weight ratios. Tensile, bending, shear and shock tests were conducted in order to reach the best types of samples that can be relied upon during the engineering designs to be applied practically[14].

In this paper, study the approximate technique of the Raleigh method is used to yield equations of natural frequency for pipes prepared from hybrid composite materials at different boundary conditions (clamped – clamped and simply supported ends) where epoxy resin as matrix is reinforced by discontinuous Kevlar fibers and carbon fibers at different volume fractions to estimate the natural frequency of the system and the critical velocity of flow at different pipe dimensions and with different volume fractions of hybrid fibers.

2. Mathematical Modeling

A straight composite pipe conveying water at length L_p includes a uniform section at thickness t and inner radius R_i, supported by pinned – pinned and clamped – clamped boundary conditions as revealed in (Fig. 1).

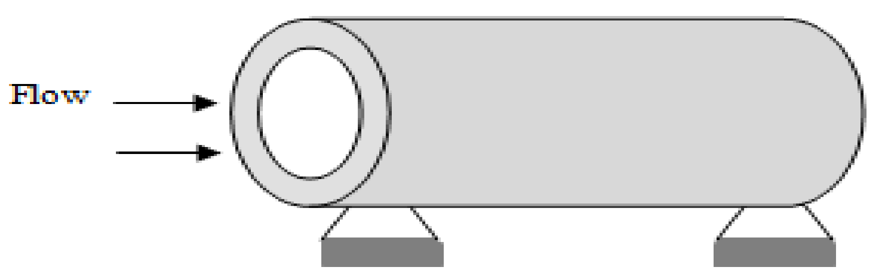

Fig. 1. Clamped – clamped of a composite pipe

The cross-section area of the composite pipe is:

$$A_{cp} = \pi * (R_o^2 - R_i^2) \qquad (1)$$

Where the outer radius of the pipe is $R_o = (R_i + t)$ and the cross-sectional area of the water flowing completely through the pipe can be explained as the following:

$$m_w = \pi * R_i^2 \qquad (2)$$

The density of composite materials evaluate as the following **[15].**

$$\rho_{cp} = \rho_f * V + \rho_{ep} * (1 - V) \qquad (3)$$

V represents the volume fraction of fibers. The density for hybrid composite material can be considered as follows:

$$\rho_{cp} = \rho_k * f_1 + \rho_c * f_2 + \rho_{ep} * (1 - f) \qquad (4)$$

The density of hybrid composite materials changes with the volume fraction of Kevlar fibers f_1, carbon fibers f_2, and resin $(1 – f)$.

Where f, represents the total volume fraction of fibers, $f = f_1 + f_2$.

Now the mass of the hybrid pipe can be written as follows:

$$m_{cp} = \rho_{cp} * A_{cp} \qquad (5)$$

While the mass of water flowing through the pipe is obtained as shown in the upcoming equation:

$$m_w = \rho_w * A_w \qquad (6)$$

To find the total mass of the system, add the mass of the pipe to the mass of the water as shown below:

$$m_{tot} = m_{cp} + m_w \qquad (7)$$

The moment of inertia for a uniform pipe can be written as below:

$$I_{cp} = \frac{\pi}{4}(R_o^4 - R_i^4) \qquad (8)$$

The equation of motion of pinned-pinned, is expressed as follows, **[16].**

$$Y_1(x) = Yo[\sin(\pi L x)] \qquad (9)$$

While the expression of motion of (clamped –clamped) is shown as below **[17].**

$$Y(x) = C\left[1 - \cos\left(\frac{2\pi x}{L}\right)\right] \qquad (10)$$

The second order of equations (9) and (10) is revealed as follows:

$$Y_1''(x) = -(\pi L)^2 Y_o \sin(\pi L x) \qquad (11)$$

$$Y''(x) = \left(\frac{2\pi}{L}\right)^2 * C\cos\left(\frac{2\pi x}{L}\right) \qquad (12)$$

By using the Raighly method the expression, of the ratio of the maximum potential energy to the maximum kinetic energy for pinned – pinned can be written as follows **[18].**

$$\omega_1 = \frac{\int_0^L E\,I(x)\,[Y_1''(x)]^2\,dx}{\int_0^L m(x)\,[Y_1(x)]^2\,dx} \qquad (13)$$

Substitution equation (9) and its second derivative in the equation (13) then integrated and simplified to obtain the natural frequency for a hybrid composite pipe filled with fluid that does not move in the pipe, as shown below:-

$$\omega_{pp} = \frac{9.859}{L_p^2}\sqrt{\frac{E_{cp} * I_{cp}}{m_{tot.}}} \qquad (14)$$

In order to obtain the equation of the natural frequency at clamped - clamped, substitution of equation (12) in the equation of motion, then integrate and simplify to get the equation of frequency for the hybrid composite pipe that contains fluid that does not move in the pipe, as shown below:-

$$\omega_{cc} = \frac{22.792}{L_p^2}\sqrt{\frac{E_{cp} * I_{cp}}{m_{tot.}}} \qquad (15)$$

E_{cp} is the modulus of elasticity of hybrid composite materials for continuous fibers according to the volume fraction of fibers, and risen can be written as follows **[19].**

$$E_{cp} = E_1 * f_1 + E_2 * f_2 + E * (1 - f) \qquad (16)$$

The following equation is used to calculate the modulus of elasticity for composite materials for aligned short fibers, **[19].**

$$E_{cp} = E_1 * \left(1 - \frac{L_c}{L}\right) + E * (1 - f) \qquad (17)$$

Therefore, the modulus of elasticity for hybrid fibers is estimated as follows:-

$$E_{cp} = (E_k * f_1 + E_c * f_2)\left(1 - \frac{L_c}{L}\right) + E_e * (1 - f) \qquad (18)$$

The critical length of fiber L_c depends on the fiber – matrix bond strength (τ_c), the diameter of the fiber (d) and fiber yield strength (σ_f). For short fiber L < 15L_c. In this study length of short fibers was taken as (L/L_C = 1, 2, 4, 8, 12, 16, 20). The study revealed that when fiber the length exceeds 15Lc, it will approach the continuous fibers.

Now, it is possible to use the following equations to estimate the critical speed of water flow through the ordinary pipe at different boundary conditions **[20].**

$$V_c = \frac{3.14}{L_p}\sqrt{\frac{E_{p*}\,I_p}{m_w}}, \quad (\text{Pinned} - \text{pinned}), \quad (19)$$

$$V_c = \frac{4.73}{L_p}\sqrt{\frac{E_{p*}\,I_p}{0.55 * m_w}}, \quad (\text{Clamped} - \text{clamped}), (20)$$

However, according to the current study that includes hybrid fibers, the previous equations 19 and 20 can be represented as follows:-

$$V_{pp} = \frac{3.14}{L_p}\sqrt{\frac{E_{cp*}\,I_p}{m_w}}, \quad (\text{Pinned} - \text{pinned}), \quad (21)$$

Vol. 33, No.2. \ 2025 ISSN: 2616 - 9916

$$V_{cc} = \frac{4.73}{L_p}\sqrt{\frac{E_{cp*}I_p}{0.55*m_w}}, \quad (\text{Clamped – clamped}), \quad (22)$$

3. Results and Discussion

The theoretical study includes different models of hybrid pipes at different wall thicknesses and diameters at different proportions of hybrid fibers that make up the pipe also at different percentages of the volumetric fraction of fibers at two types of boundary conditions as simply supported and clamped–clamped. Rayleigh's approximate method can be used in the present paper to estimate the natural frequency of the hybrid pipe conveying water. Four models for hybrid composite pipes were studied in this research for a one-meter-length pipe with the dimensions shown in Table1. Table 2 shows the mechanical properties of different materials used in this study. Table 3 shows a theoretical comparison between the current study and another theoretical study conducted by researcher Etim 2018 on a plastic pipe with the following specifications at different water flow velocities through the pipe: inner diameter = 0.006m , outer diameter=0.0097m, modulus of elasticity = 2092400Pa and density =1128 kg/m3.

Table 1. Dimensions of models

Model No.	Inner Radius, Ri, cm	Thickness, t, mm
1	2	2
2	2	3
3	3	2
4	3	3

Table2. Properties of materials **[21]**

Materials	Modules of elasticity, E (Gpa)	Mass density, ρ (kg/m^3)
Epoxy	3.5	1540
Kevlar	154	1470
Carbon	224	1750

Table 3. Natural frequency (rad/sec) of plastic pipe. Etim S Udoetok, **[22]**

Vf (m/sec)	Geometric Analysis ω(rad/sec), Etim S Udoetok	Present work ω(rad/sec)	Difference δ%
0	14.751	16.841	12.4%
1.54	14.621	16.694	12.4%
3.07	14.228	16.263	12.5%
4.34	13.685	15.626	12.4%
5.42	13.051	14.902	12.4%
6.43	12.291	14.035	12.4%
7.19	11.594	13.240	12.4%

Difference δ% = [(Rayleigh's method – Geometric Analysis) / Rayleigh's method]*100%

Figures from 2 to 9 show the natural frequency change with the ratio of fiber length to the volume fractions of hybrid fibers equal to 40% at variable volume fraction of carbon and Kevlar fibers. At different proportions between carbon fibers and Kevlar fibers in hybrid pipes, the frequency increases with the increase in the fibers length, the thickness of the wall of the pipe and the diameter, also with the increasing proportion of carbon fibers in the hybrid pipes due to the increase in the moment of inertia of the pipe, which leads to an increase in the stiffness of the system. Carbon fibers have high elastic modulus, high strength, lightweight, and good flexibility that cause an increase in the natural frequency of the pipes. The models that contain only a fractional volume of Kevlar fibers have a natural frequency lower than that of models that contain a fractional volume of carbon fiber only. This is attributed to the low stiffness of Kevlar fibers compared to carbon fibers, which leads to a decrease in the elastic modulus of the model, thus causing significant deformity of the pipe during vibration with increased damping of the vibrating system. The type of fixation at both ends of the pipe has a considerable effect on the natural frequency, as the pipe with a clamped – clamped fixation has a natural frequency greater than the pipe with pinned – pinned fixation as a result of the increased moment of bending at the clamped end due to the prevention of moment rotation**.** Figures 10 to 13 show the effect of the dimensions of the composite pipes, as well as the effect of the volume fraction of the fibers used in the hybrid pipes on the critical speed for different boundary conditions. It can be observed that the critical speed of flow increases with an increase in the thickness and radius of the pipe. In addition, the critical speed of flow increases with an increase in the volume fraction of the carbon fibers in hybrid pipes.

The critical speed of the flow in the hybrid pipes increases when the percentage of carbon fibers is increased, while the percentage of Kevlar fibers is decreased, which causes an increase in the stiffness of the pipes. This is due to the increased flexibility of the pipes, which increases the endurance by increasing the flow speed of the fluid passing through the hybrid pipes. It can be noted that the method of fixation of the two ends of the pipe has a clear effect on the critical flow speed of the fluid passing through the pipes, as the pipes that are in clamped – clamped ends have the ability to withstand a higher flow speed of water than the pinned-pinned ends, and this is due to the possibility of preventing the bending rotation at the end of the clamped kind due to increased bending moment. Figures 14 to 19 show the change in the natural frequency of the pipes with the change in the fiber length ratio for different values of the wall thickness and the radius of the pipe at a volume fraction of the fibers of 60%. In the case of pure fibers as well as hybrid fibers, it can be observed that the pipe behaves with all variables in the same manner in the case of using the fiber ratio of 40 percent, as noticed an increase in the natural frequency values as a result of the increased stiffness of the pipes due to the increase in the percentage of fibers that leads to an increase in the flexibility of the pipe. Figures 20 to 23 represent the change of critical velocity of water flow according to the length ratio of fibers at a volume fraction of 60% fibers with different dimensions of hybrid fibers. It is clear that the behavior is similar to that of 40% fibers, except that there is an increase in the amount of critical velocity that the pipe can withstand due to the increase in the fiber percentage, which is the main reason for strengthening the pipe material in withstanding the increase in the critical velocity of the fluid flow, which causes an increase in its stiffness.

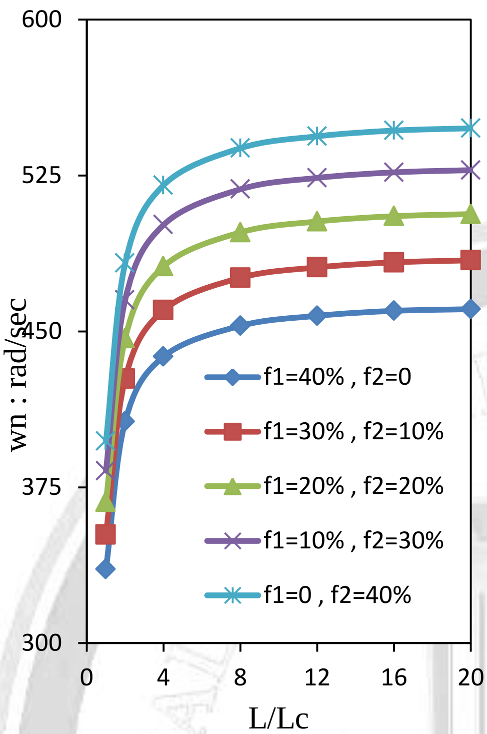

Fig. 2. Simply support, t=2mm, Ri=2cm

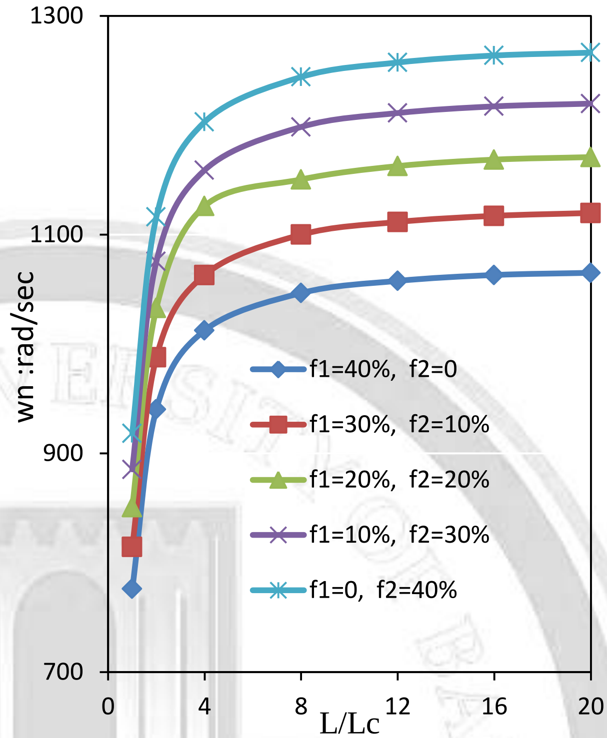

Fig. 3. Clamped-clamped, t=2mm, Ri=2cm

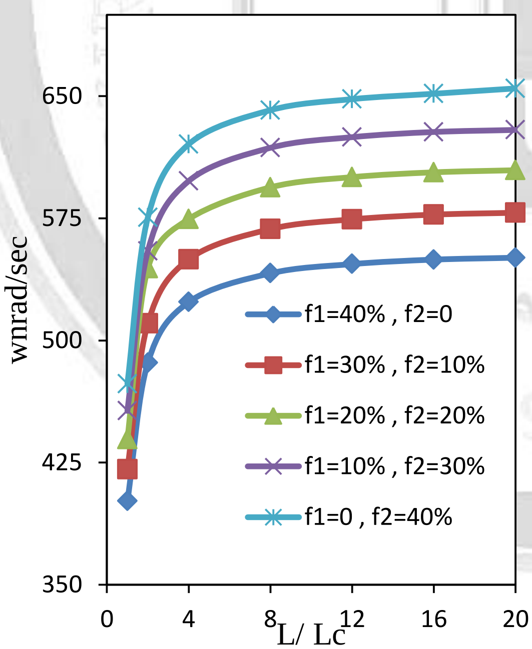

Fig.4. Simply support, t=3mm, Ri=2cm

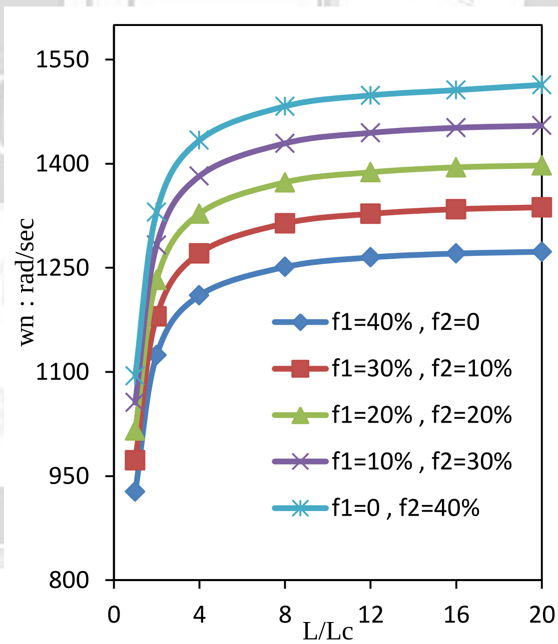

Fig. 5. Clamped-clamped, t=3mm, Ri=2cm

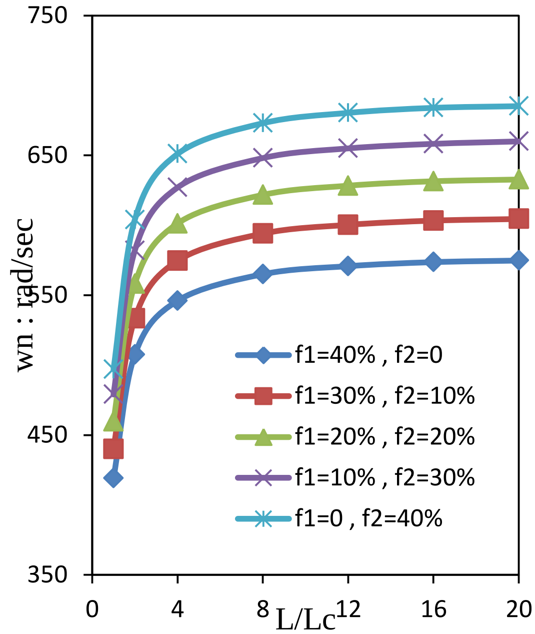

Fig. 6. Simply support, t=2mm, Ri=3cm

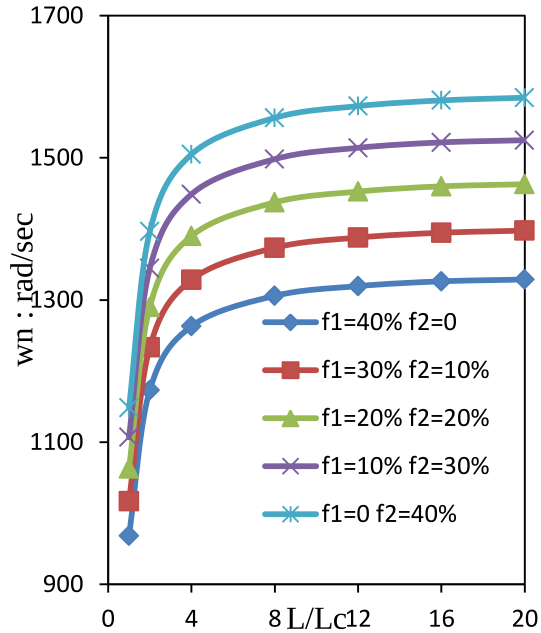

Fig. 7. Clamped – clamped t=2mm, Ri=3cm

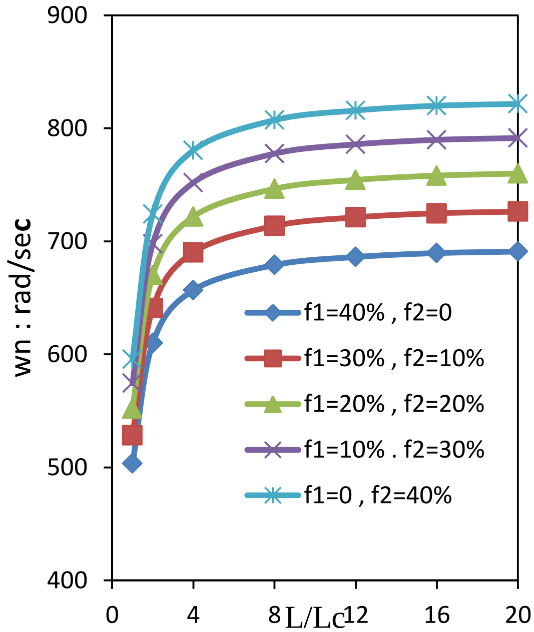

Fig. 8. Simply support, t=3mm, Ri=3cm

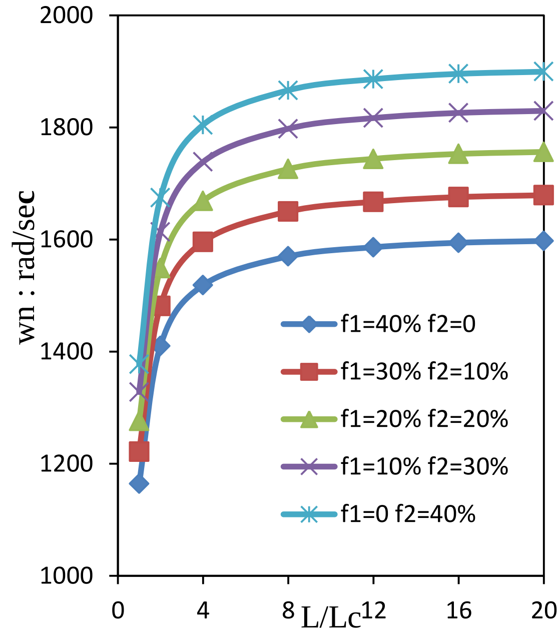

Fig. 9. Clamped - clamped, t=3mm, Ri=3cm

Vol. 33, No.2. \ 2025 ISSN: 2616 - 9916

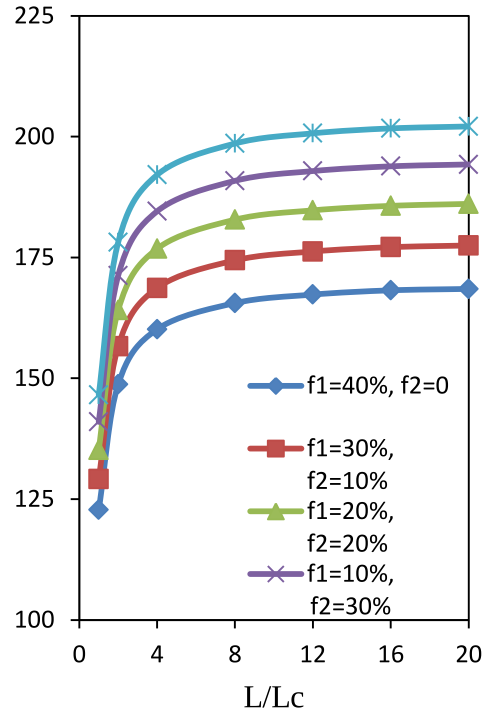

Fig. 10. Simply support, t=2mm, Ri=2cm

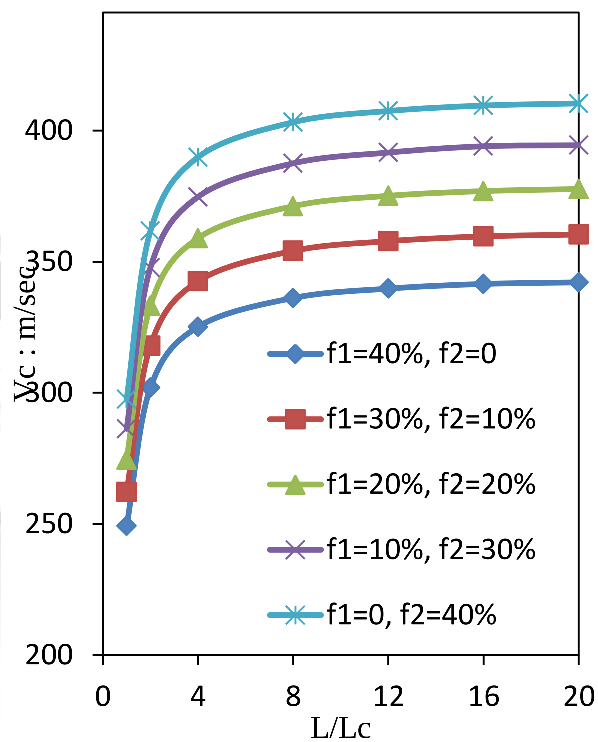

Fig. 11. Simply support, t=3mm, Ri=3cm

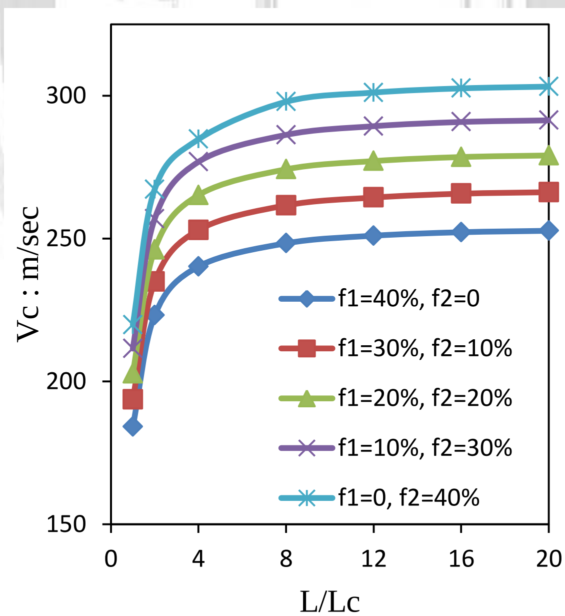

Fig. 12. Clamped – clamped, t=2mm, Ri=2cm

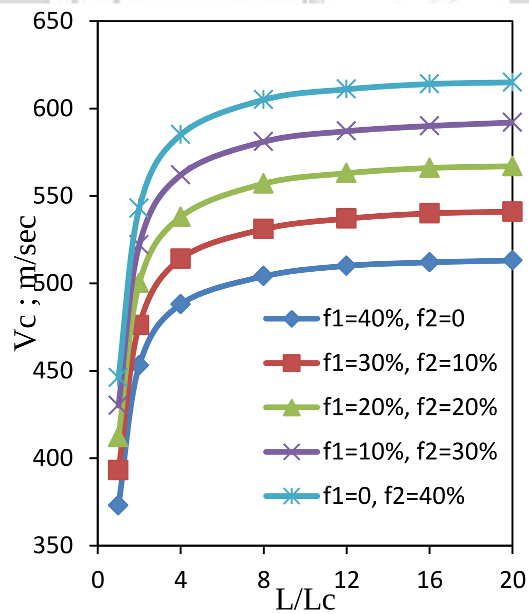

Fig. 13. Clamped – clamped, t=3mm, Ri=3cm

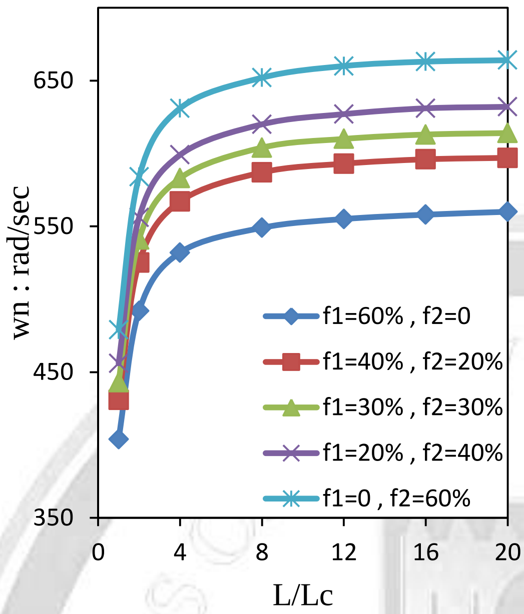

Fig. 14. Simply support, t=2mm, Ri=2cm

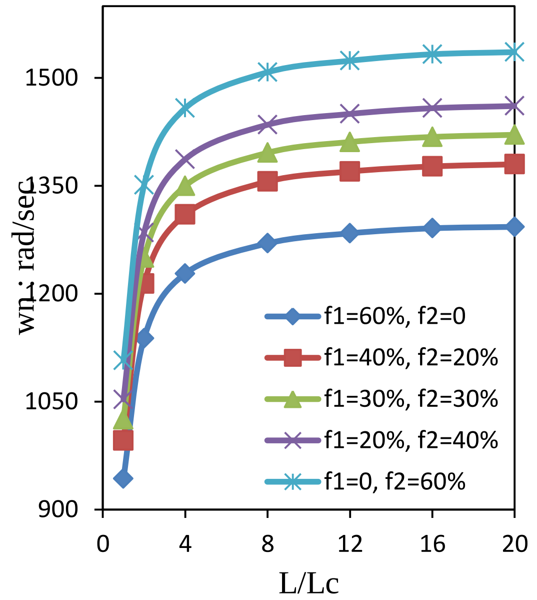

Fig. 15. Clamped – clamped, t=2mm, Ri=2cm

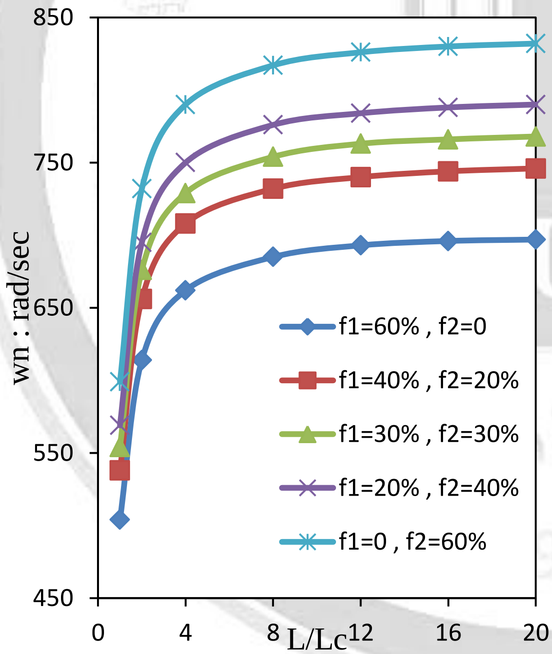

Fig. 16. Simply support, t=2mm, Ri=3cm

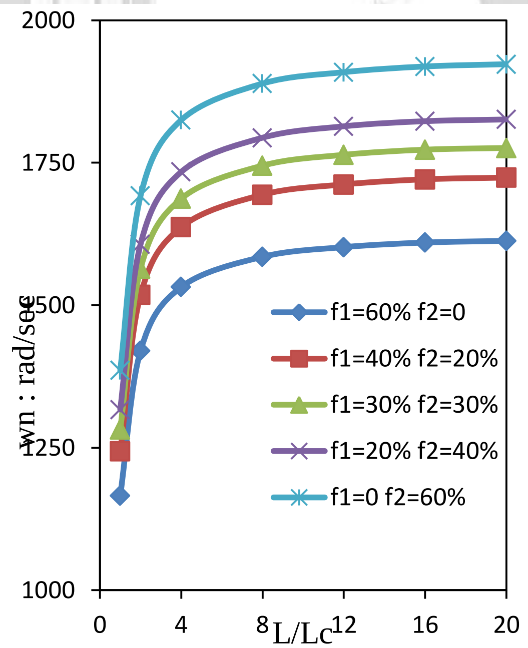

Fig. 17. Clamped – clamped, t=2mm, Ri=3cm

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Vol. 33, No.2. \ 2025 ISSN: 2616 - 9916

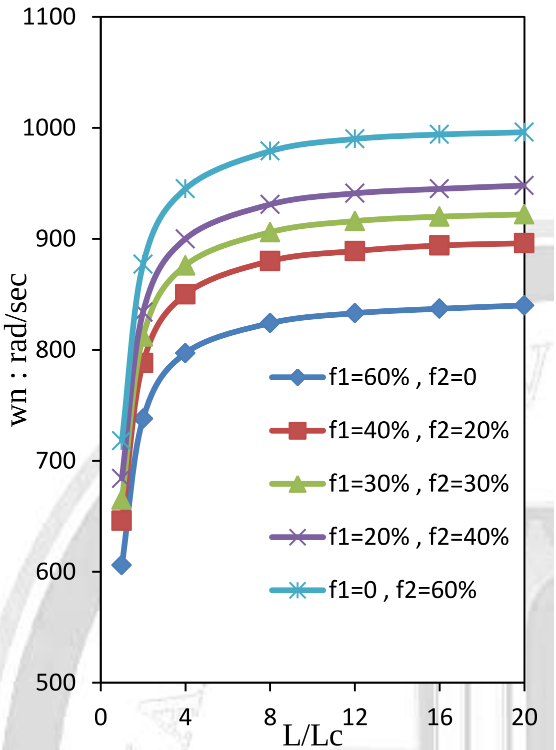

Fig.18. Simply support, t=3mm, Ri=3cm

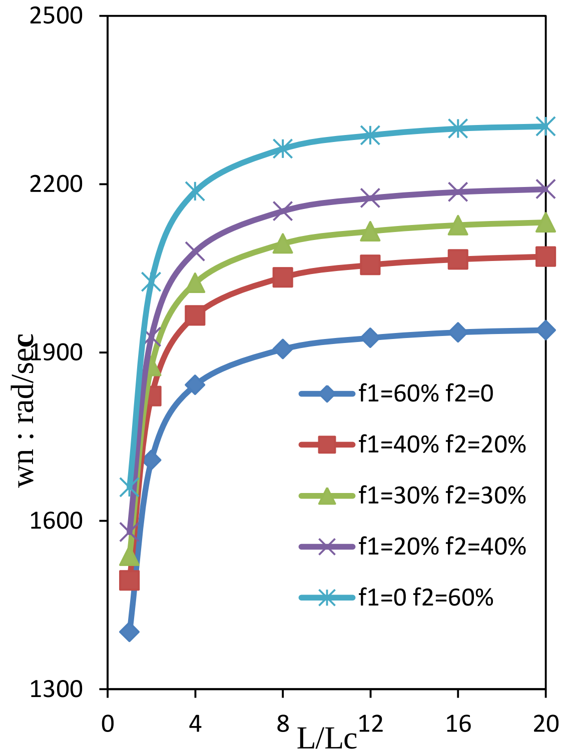

Fig.19. Clamped–clamped, t=3mm, Ri=3cm

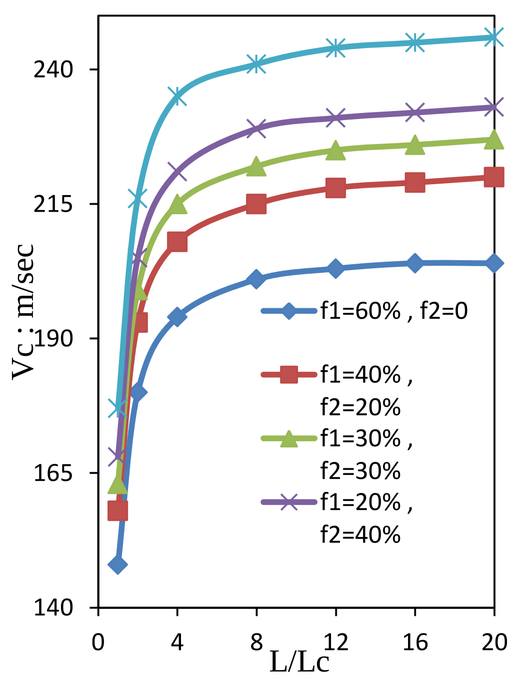

Fig. 20. Simply support, 2mm, Ri=2cm

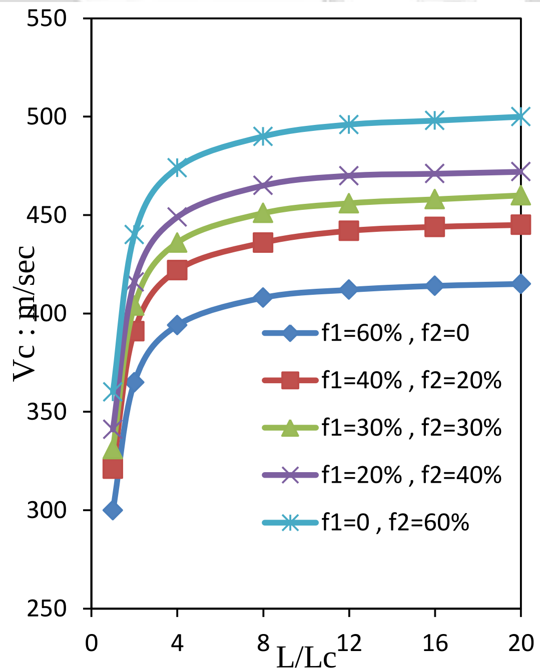

Fig. 21. Clamped – clamped, t=2mm, Ri=2cm

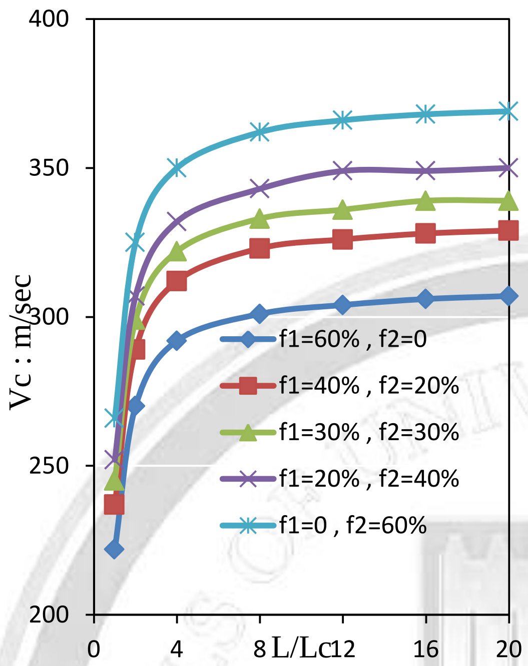

Fig. 22. Simply support, t=3mm, Ri=3cm

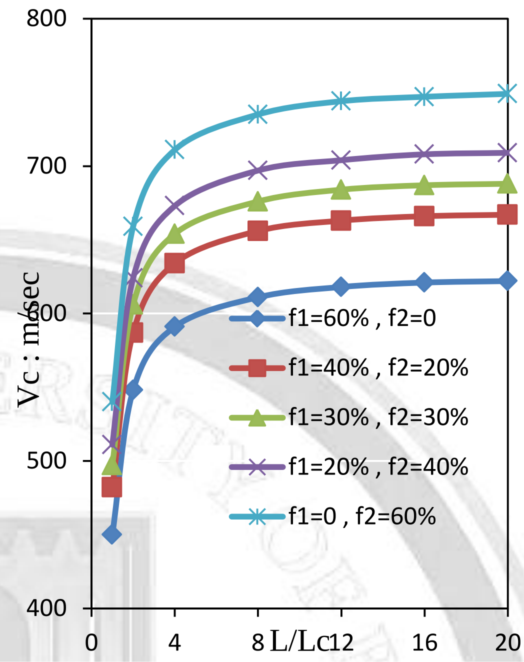

Fig. 23. Clamped – clamped t=3mm, Ri=3cm

5. Conclusion

In the present research, the flow of water- induced vibrations of the circular cross-section of the hybrid pipe at different boundary conditions was studied. The Rayleigh method was suitable for use in this paper. The study included using the carbon fibers with Kevlar fibers at different volume ratios in order to obtain different designs of composite pipes for transporting fluids at volume fraction of 40% and 60%. The construction of the pipe was for different diameters as 2cm, 3cm and have wall thicknesses as 2mm, 3mm at one-meter length. The study showed that the natural frequency and critical velocity increase with increasing the thickness of the pipe wall, the diameter, and the increasing length ratio of the fibers, the enhancement of the percentage of natural frequency range from 4.9% , 9%, 12.6% to 15.8% while for critical velocity from 4.9% , 9.4%, 13.2% to 16.6 % where the behavior of the pipe from carbon fibers is better than that made from Kevlar fibers and hybrid pipes.

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السلوك الديناميكي لأنابيب نقل المياه الهجينة المقواة بالإيبوكسي المصنوعة من مادةالكيفالر/الكربون

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الخلاصة

تضمن البحث دراسة تأثير التسليح بالألياف الهجينة المقطعة المكونة من ألياف الكيفلار وألياف الكربون مع راتنج الإيبوكسي على التردد الطبيعي لأنابيب نقل المياه، وكذلك تأثيره على أقصى سرعة تدفق للمياه عبر الأنابيب والمعروفة بالسرعة الحرجة، لظروف حدودية مختلفة متمثلة, مفصل, مفصل – مفصل والمثبت – المثبت. تم تسليح راتنج الإيبوكسي بألياف كيفلار مقارنة بالنموذج المقوى بألياف الكربون بنفس النسب الحجمية. يعتمد طول الليف القصير على النسبة بين طول الليف القصير والطول الحرج لليف القصير كما موضح (L/Lc=1, 2, …and 20). للحصول على مادة مركبة هجينة تم دمج كل من ألياف الكربون وألياف كيفلار مع مادة الراتنج بنسب مختلفة. في النماذج المهجنة , الهياكل تمتلك جساءة عالية لمقاومة اجهاد الشد بسبب الياف الكربون بالإضافة لذلك فان وجود الياف الكفلار في النماذج يعزز من متانة النموذج في مقاومة الصدمات الخارجية. تم إجراء الحسابات باستخدام البرنامج الرياضي (MATLAB) وفقًا لطريقة تقريب رايلي. لوحظ أن التردد الطبيعي للنظام والسرعة الحرجة للتدفق أكبر في نموذج ألياف الكربون من تلك الموجودة في نموذجي الياف الكيفلار والألياف الهجينة. تم دراسة تأثير تغيير سمك وقطر النماذج على السلوك الديناميكي لأنبوب بطول متر واحد، وقد أظهرت الدراسة أن التردد الطبيعي والسرعة الحرجة تزداد مع زيادة سمك وقطر جدار الأنبوب، وذلك تبعاً لنوع التثبيت. النسبة المئوية في تحسين التردد الطبيعي للانبوب عند مقاطع عرضية مختلفة تتراوح من 4.9% , 9%, 12.6% to 15.8% حيث انها ترتفع مع زيادة الكسر الحجمي لألياف الكربون في المواد المركبة المهجنة وعند أوضاع تثبيت مختلفة. بخصوص تحسين النسبة المئوية للسرعة الحرجة التي تتراوح من 4.9% , 9.4%, 13.2% to 16.6% حيث انها تتحسن مع زيادة اكسر الحجمي لألياف الكربون في الأنبوب المهجن ، وتم إجراء مقارنة نظرية مع بحث استخدم نموذجاً بأبعاد مختلفة، وكانت النتائج بفارق مقبول.

الكلمات الدالة: الإيبوكسي، ألياف الكربون، ألياف الكيفلار ، الأنابيب الناقلة للمائع, الألياف الهجينة، نسبة الطول.

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