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Dynamical Analysis of Non-Metallic (Glass, Carbon) Fiber Reinforced Concrete under the Influence of Vibration

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Abstract The process of molding fiber reinforced concrete will be clearly convenient if the use of appropriate vibration techniques, and also can be obtained on the distribution of semi-uniform and appropriate orientation of fibers within the fresh concrete. Glass fiber has strongly property drink water, and big amount of water within fresh concrete will be absorbed by glass fiber, and therefore low workability, as well as a random distribution and orientation of fiber usually occurs in the traditional mixtures of fiber reinforced concrete (FRC). Tensile strength and post-cracking behavior of non-metallic (glass or carbon) fiber reinforced concrete structures can be improved by control the distribution and the orientation of fiber within concrete matrix using vibration methods. In this paper is to provide a dynamical model for the process of casting fiber-reinforced concrete on a vibration table, with an analytical study from which to predict the movement of fiber within the fiber-reinforced concrete mixture during the casting process. This study also explains the possibility of controlling the distribution and orientation of the fiber within the fresh concrete during the Single fiber casting process or in the form of bundles, in addition to the numerical example.

Keywords Fiber Reinforced Concrete (FRC), Glass Fiber, Carbon Fiber, Vibration, Fresh Concrete

1. Introduction

This Development production of non-metallic fiber (glass, carbon) reinforced concrete with high-strength matrix (compressive strength 70 MPa to 140 MPa) should be done during tasks of mix design, mixing sequence and vibration procedure.

Basic principles for fiberconcrete still the same like for conventional concrete. Fibers are observed as aggregates with specific elongated form. The main common principles are: Low water/cement ratio; aggregate packing based on "ideal" grading curves; water content determination on the principle of absolute volumes[1].

While situation of unstable cracks propagation is acquired soon in loaded unreinforced concrete matrix, cracks can be bridged by fibers, in the case of FRC, and the material can carry loads far beyond the plain concrete matrix cracking. Such short fibers may be metallic – steel and non-metallic - glass, carbon and aramid. High tensile load bearing capacity requires large fiber percentage in the structure of material, what immediately leads to noticeable decrease of fresh FRC workability[2].

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Glass fiber has strongly property drink water, and big amount of water within fresh concrete will be absorbed by glass fiber, and therefore low workability, as well as a random distribution and orientation of fiber usually occurs in the traditional mixtures of fiber-reinforced concrete FRC (see Fig 1.1). The process of molding fiber reinforced concrete will be clearly convenient if the use of appropriate vibration techniques, and also can be obtained on the distribution of semi-uniform and the appropriate orientation of fiber within the fresh concrete (see Fig 1.2).

Figure 1.1. AR glass fiber concrete mix

This paper is to provide a dynamical model for the process of the casting of the fiber reinforced concrete on vibration table, with an analytical study from which to predict the movement of fiber within the fiber-reinforced concrete mixture during the casting process. This study also explains the possibility of controlling the distribution and the direction of the fiber within the fresh concrete casting process in two cases of the fiber (single and bundle), in addition to the numerical example.

Figure 1.2. The same mix using vibration road

2. Materials and Methods

2.1. Mixing and Casting Rationalization under Vibration

The benefit of the vibration in improving the process of casting for non-metallic fiber reinforced concrete seems manifestly clear that when using rod vibration within the fresh concrete or casting procedure above the vibration table (see Fig 1.1, 1.2), This vibration causes the return water from the fiber to the concrete mix leading to improved workability.

The use of appropriate vibration techniques like vibration table can be used also to control the movement and distribution of fiber inside the fresh concrete mixture. In this paper a dynamic model is created for the process of casting fiber reinforced concrete on a vibration table (see Fig 2.1.1).

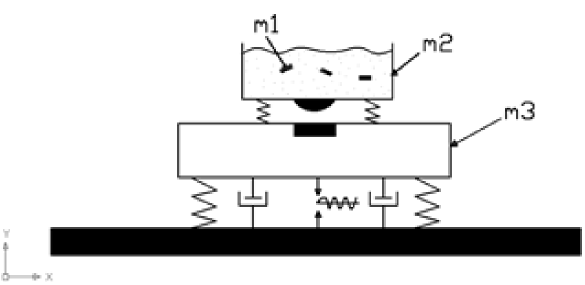

Figure 2.1.1. Dynamical model of casting on vibration table; where: m1 = glass fiber bundle mass; m2 = steel mould and concrete mixture mass; m3 = vibration table mass

2.2. Dynamical Analysis of Glass Fiber Movement inside Concrete Composite

Random distribution and orientation of fiber usually occurs in the traditional mixtures of fiber reinforced concrete FRC. This dynamical analysis explains the possibility of controlling the distribution and orientation of the fiber inside the fresh concrete during the Single fiber casting process or in the form of bundles.

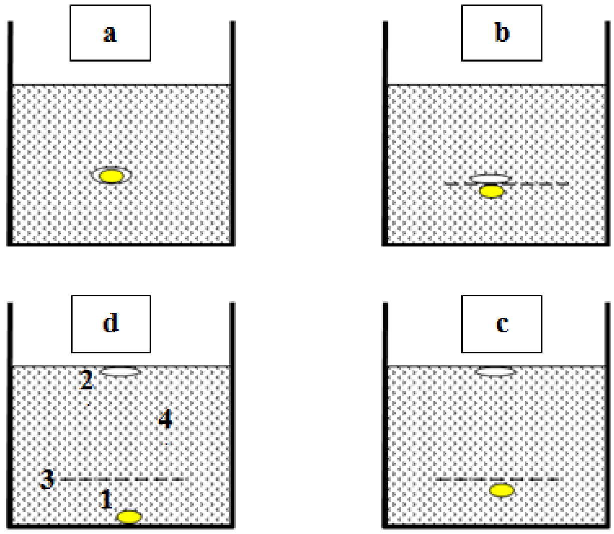

Figure 2.2.1. Expected movement of glass fiber and water particles under the influence of vibration; where: 1 = glass fiber particle; 2 = water particle; 3 = comparison level; 4 = concrete mixture

The expected movement of a particle of water and fiber glass particle can be traced through the following stages (see Fig 2.2.1):

a. Glass fiber drink water particle during the process of mixing reinforced concrete components prior to the application of vibration forces. Static forces acting on the glass fiber particle is both the weight force W1 and Archimedes force Ar1 in vertical direction, and the forces W2, Ar2 acting on the water particle in vertical direction also (see Figure 2.2.2).

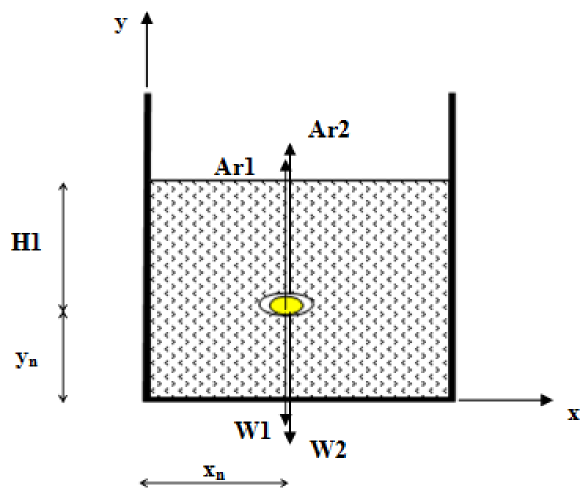

Figure 2.2.2. Static forces acting on glass fiber particle and the water particle

b. Under the influence of vibration begins the particle water and glass fiber particle separation from each other because of the difference in specific weight values for each of these two materials.In vertical direction normal force N1 acting on each particle, and friction force f1 acting on the interface between these two particles and the fresh concrete. Also normal force N2 and friction force f2 acting on the particles in horizontal direction (see Figure 2.2.3).

c. Water particle floats on the surface and the glass fiber particle descend downwards under the influence of vibration during the mixing process or casting.

d. In the end water particle floats on the surface and the glass fiber particle settles below.

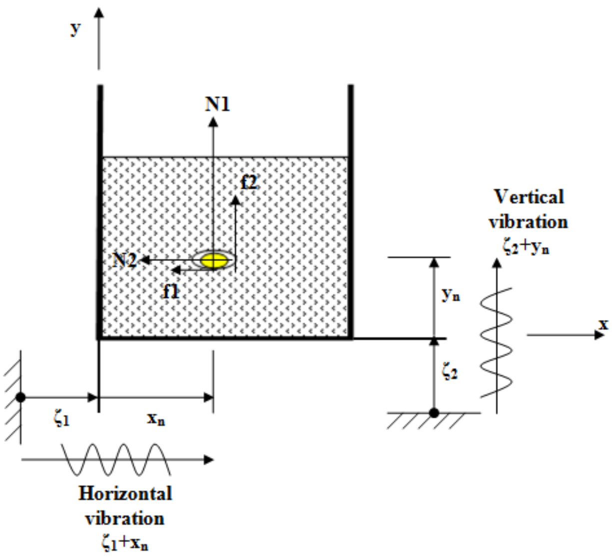

Figure 2.2.3. Normal and friction forces acting on glass fiber particle and the water

According to Newton's law:

$$m \, . \, \bar{a} = \Sigma \, \overline{F}$$

In (x) direction we can write:

x:

$$m \, . \, \ddot{x} = \Sigma \, \overline{F}_1$$

$$x = \zeta_1 + x$$

$$\dot{x} = \dot{\zeta}_1 + \dot{x}$$

$$\ddot{x} = \ddot{\zeta}_1 + \ddot{x}$$

Where the vibration equation of horizontal movement ζ_1 is:

ζ_1 = A1.sin (ω.t) +A2.sin (k.t+α1)

$\dot{\zeta}_1$= A1.ω.cos (ω.t)+A2.k.cos (k.t+α1)

$\ddot{\zeta}_1$ =-A1.ω2.sin (ω.t)-A2.k2.sin (k.t+α1)

In (y) direction we can write also:

y:

$$m \, . \, \ddot{y} = \Sigma \, \overline{F}_2$$

$$y = \zeta_2 + y$$

$$\dot{y} = \dot{\zeta}_2 + \dot{y}$$

$$\ddot{y} = \ddot{\zeta}_2 + \ddot{y}$$

Where the vibration equation of vertical movement ζ_2 is:

ζ_2 = A3.sin (ω.t)+A4.sin (k.t+α2)

$\dot{\zeta}_2$ = A3.ω.cos (ω.t)+A4.k.cos (k.t+α2)

$\ddot{\zeta}_2$ = -A3.ω2.sin (ω.t)-A4.k2.sin (k.t+α2)

For the water particle:

$$m_1 \, . \, \ddot{x} = -k_{01}.v_1 - k_1.H1.sing\,(v_1) + A1.\omega^2.\sin\,(\omega.t) + A2.k^2.\sin\,(k.t+\alpha_1)$$

$$m_1 \, . \, \ddot{y} = -V2.g.\,(\rho_1-\rho_0) + (-k_{01}.v_1 - k_1.H1.sing\,(v_1) + A3.\omega^2.\sin\,(\omega.t) + A4.k^2.\sin\,(k.t+\alpha_2))$$

For glass fiber particle:

$$m2 \, . \, \ddot{x} = -k_{02}.v_2 - k_2.H1.sing\,(v_2) + A1.\omega^2.\sin\,(\omega.t) + A2.k^2.\sin\,(k.t+\alpha_1)$$

$$m2 \, . \, \ddot{y} = -V2.g.\,(\rho_2-\rho_0) + (-k_{02}.v_2 - k_2.H1.sing\,(v_2) + A3.\omega^2.\sin\,(\omega.t) + A4.k^2.\sin\,(k.t+\alpha_2))$$

Previous equations can be represented by this matrix form:

$$\begin{pmatrix} x1_0 \\ v1x_0 \\ x2_0 \\ v2x_0 \\ y1_0 \\ v1y_0 \\ y2_0 \\ v2y_0 \end{pmatrix} := \begin{pmatrix} 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \end{pmatrix}$$

$$\begin{pmatrix} x1_{n+1} \\ v1x_{n+1} \\ x2_{n+1} \\ v2x_{n+1} \\ y1_{n+1} \\ v1y_{n+1} \\ y2_{n+1} \\ v2y_{n+1} \end{pmatrix} := \begin{bmatrix} x1_n + s\cdot v1x_n \\ v1x_n + \frac{s}{m1}\cdot\left(-k01\cdot v1x_n - k1\cdot H1\cdot \mathrm{sign}(v1x_n) + A1\cdot\omega^2\cdot\sin(\omega\cdot t_n) + A2\cdot k^2\cdot\sin(k\cdot t_n + \alpha1)\right) \\ x2_n + s\cdot v2x_n \\ v2x_n + \frac{s}{m2}\cdot\left[0 + \left(-k02\cdot v2x_n - k2\cdot H1\cdot \mathrm{sign}(v2x_n) + A1\cdot\omega^2\cdot\sin(\omega\cdot t_n) + A2\cdot k^2\cdot\sin(k\cdot t_n + \alpha1)\right)\right] \\ y1_n + s\cdot v1y_n \\ v1y_n + \frac{s}{m1}\cdot\left[-V1\cdot g\cdot(\rho1 - \rho0) + \left(-k01\cdot v1y_n - k1\cdot H1\cdot \mathrm{sign}(v1y_n) + A3\cdot\omega^2\cdot\sin(\omega\cdot t_n) + A4\cdot k^2\cdot\sin(k\cdot t_n + \alpha2)\right)\right] \\ y2_n + s\cdot v2y_n \\ v2y_n + \frac{s}{m2}\cdot\left[-V2\cdot g\cdot(\rho2 - \rho0) + \left(-k02\cdot v2y_n - k2\cdot H1\cdot \mathrm{sign}(v2y_n) + A3\cdot\omega^2\cdot\sin(\omega\cdot t_n) + A4\cdot k^2\cdot\sin(k\cdot t_n + \alpha2)\right)\right] \end{bmatrix}$$

Where:

$$t_n := n\cdot s$$

n: steps number in process.
s: size of one step in process.

$$k1 := \frac{0.1\cdot m1\cdot g}{H1}$$

$$k2 := \frac{0.1\cdot m2\cdot g}{H1}$$

W1: weight of the water particle.
W1 = m1. g
m1: mass of the water particle.
m1 = V1. ρ1
V1: volume of the water particle (m^3).
ρ1: specific weight of the water (= 1 t/m^3).
W2: weight of glass fiber particle.
W2 = m2. g
m2: mass of glass fiber particle.
m2 = V2. ρ2
V2: volume of glass fiber particle (m^3).
ρ2: specific weight of glass fiber (= 2.7 t/m^3).
g: ground gravity (= 9.81 m/sec^2).
ρ0: specific weight of concrete (t/m^3).

K01: viscosity damping factor between the water and the concrete.
k1: dry friction factor between the water and the concrete (k1= 0 at the free surface of the composite).
K02: viscosity damping factor between the glass fiber and the concrete.
k2: dry friction factor between glass fiber and the concrete.
H1: vertical distance between the center of the studied particle and the free surface of the composite.
N1: normal force acting on the studied particle in vertical direction.
N2: normal forces acting on the studied particle in horizontal direction.
f1: friction force acting on the particle horizontally.
f2: friction force acting on the particle vertically.
v1: relative velocity of the water particle.
v2: relative velocity of glass fiber particle.

3. Results and Discussion

The previous analytical study of glass fiber reinforced concrete mixes can be applied in the case of carbon fiber with taking into account the need to re-adjust the values of the factors which are related with the material type of the fiber.

Numerical results can be obtained depending on the previous analytical study, where the changing of materials properties and the modifying of vibration's equation in each direction, all of that will give the possibility to control the movement of fiber inside the freshly concrete matrix during the process of mixing and casting.

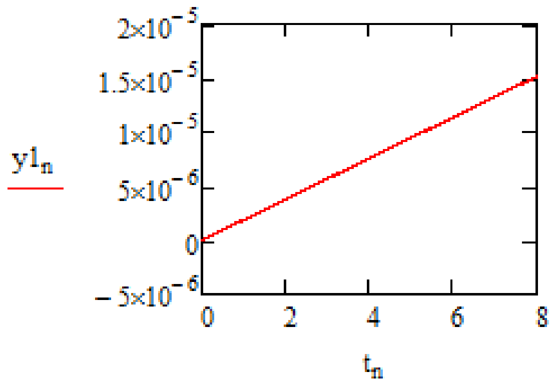

Figure 3.1. The water particle movement in time

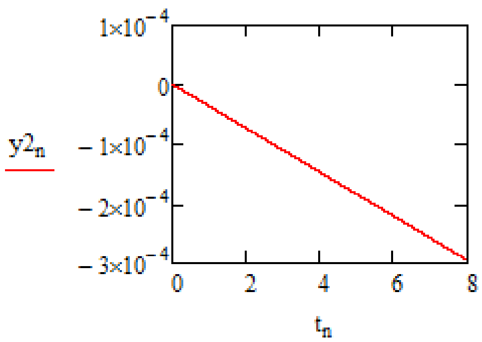

Figure 3.2. Glass fiber particle movement in time

As a numerical example in the case of single glass fiber, let's assume diameter of glass fiber = 0.01 mm and length = 12 mm inside freshly concrete matrix, the water thickness around glass fiber = 10 % of the diameter of glass fiber.

Numerical results and curves can be obtained depending on our previous dynamical model and analytical study, these results will describe the movement of glass fiber and the water inside freshly concrete matrix during the process of casting under the influence of vibration (see Figures 3.1, 3.2, 3.3, 3.4, 3.5, 3.6, 3.7, 3.8).

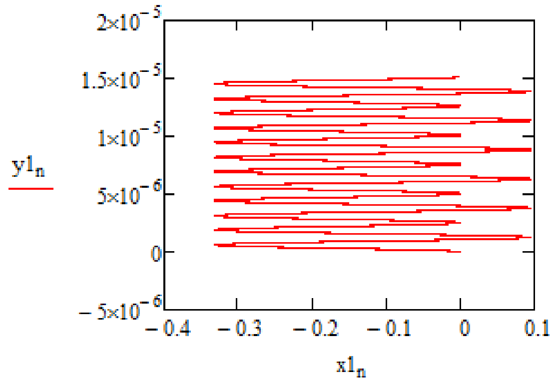

Figure 3.3. The water particle movement in coordinates

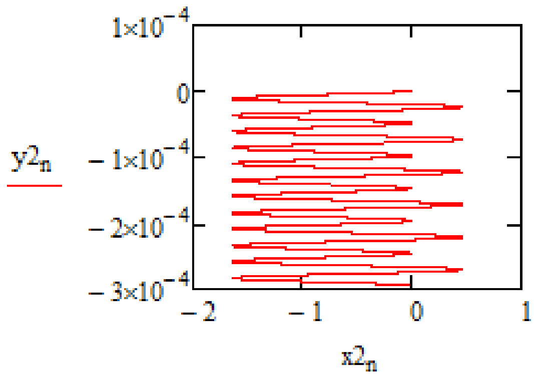

Figure 3.4. Glass fiber movement in coordinates

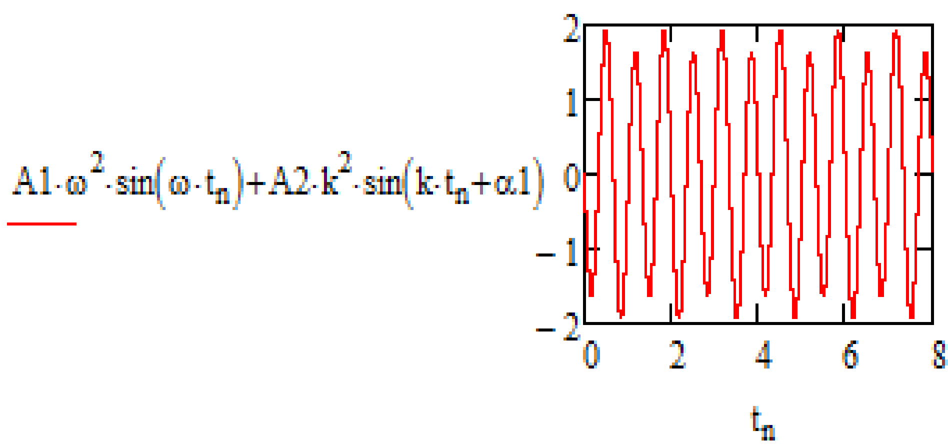

Figure 3.5. Horizontal vibration

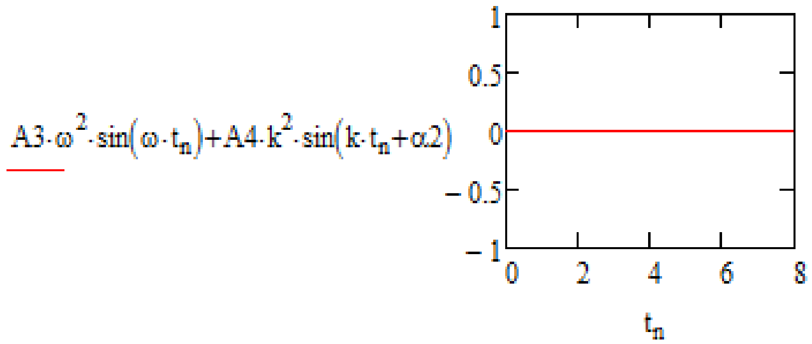

Figure 3.6. Vertical vibration

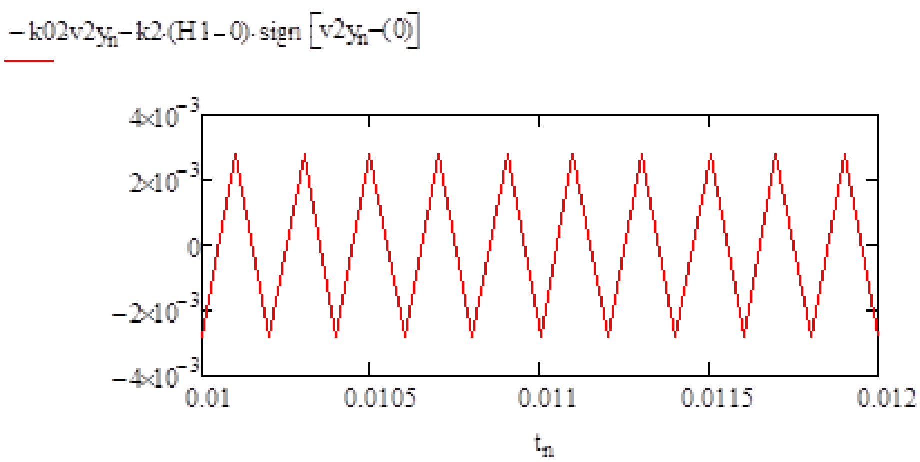

Figure 3.7. Viscosity and dry friction forces acting on the glass fiber particle

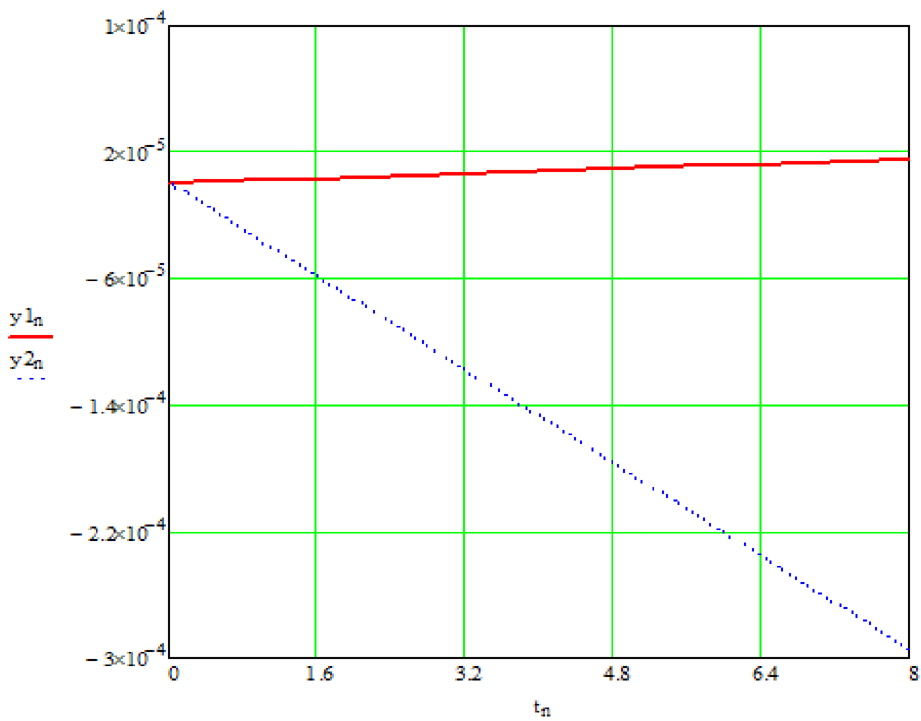

Figure 3.8. The movement of water particle compared with the movement of glass fiber particle in time

Results

1. When the value of Archimedes driving force Ar1 acting on the water particle (which is located on the glass fiber and separated it under the influence of vibration) is greater than the weight of this particle of water W1, the water particle movement will be towards the top in the fresh concrete until it reaches the surface.

$$Ar1 \text{ (acting on the water)} = V1.\ \rho 0.\ g > W1$$

⟹ water particle will be toward the top

2. When the value of Archimedes driving force Ar2 acting on the glass fiber is smaller than this particle weight W2, the glass fiber particle movement will be downwards into the fresh concrete under the influence of vibration.

$$Ar2 \text{ (acting on the glass fiber)} = V2.\ \rho 0.\ g < W2$$

⟹ glass fiber particle will be down warded into concrete

3. In the case of carbon fiber the movement of the fiber within the fresh concrete will be upwards due to the fact that its specific weight (1750 kg/m^3) is smaller than the specific weight of the fresh concrete (2300 kg/m^3), whereas in the case of the glass fiber the fiber will take opposite direction due to its specific weight, where the specific weight of glass fiber (2700 kg/m^3) which is greater than the fresh concrete.

4. Conclusions

- Preparing non-metallic fiber reinforced concrete mixes using traditional methods leads to stiff and low workable mixes.
- Convenient mixing and casting of non-metallic fiber reinforced concrete mixes might be obtained using appropriate vibration techniques.
- Semi-uniform distribution and appropriate orientation of fibers within the fresh concrete can be obtained under the influence of vibration.
- Using the vibration methods, the tensile strength and the post-cracking behavior of the non-metallic (glass or carbon) fiber reinforced concrete structures might be improved by control of the fiber distribution and orientation inside the concrete matrix.
- Under the influence of vibration, the movement of fiber and water within the fresh concrete is related with its specific weight in comparison with the specific weight of the fresh concrete.

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