Simplified Measurement of Density of Irregular Shaped Composites Material using Archimedes Principle by Mixing Two Fluids Having Different Densities

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Abstract - *Density is an important physical parameter used to judge the properties related to the sustainability of reinforcement of composite materials. A new simplified density measurement technique for irregularly shaped specimens using the Archimedes principle is presented in the present research work. For this purpose, two fluids having Different Densities are mixed and density is calculated. The method gives an advantage in the measurement of the density of composite with varied compositions. The density of the specimen is equal to the density of liquid displaced.*

Keywords: Density, Archimedes principle, buoyancy, Composite, irregular objects, fluids

1.0 INTRODUCTION

In designing technical textiles like textile reinforced composites, one of the major parameters is density. To judge the suitability of engineering composites properties like stiffness, strength, structural equivalence and cost-effectiveness, the density is to be studied. For this task, density becomes an important parameter [1]. Density is also required to be known for estimating composite weight and evaluate fibre content as well as void content for property predictions. The fibre volume and void content are very important for the quality control of composite materials.

1.1 Density

Density is the average mass per unit volume. It can be determined by dividing mass of sample with volume of the sample [2]. Determining the mass of a sample is a simple task but finding volume is a difficult task. It is convenient to report density values in terms of specific gravity. Specific gravity, also called relative density, is the ratio of the density of a substance to that of given reference material. If the reference is not specifically stated then it is normally assumed to be water for solid and liquid, at its densest (at 4 °C water has a density of 1.0 kg per liter) [3].

1.2. Measurement methods of density for composites

Different techniques are used traditionally to measure density of composites. Different measurement methods like Archimedes (buoyancy), density gradient columns, Helium pycnometry and Liquid pycnometry were suggested for measurement of density [4,5,6,7]. Out of different density measuring techniques, the following are five different methods considered to be of high performance (commonly preferred) [4].

1.2.1. Measuring the dimensions of the composite sample. Density of composite can be calculated using the specimen dimension and mass for regular-shaped objects. This method is included in an ASTM standard [8,9]. Soykeabkaew et al (2004) used this method for fibers having known length. In this method, the cross-section of specimen was assumed to be uniform [10]. This assumption is not correct for most of the hand lay composites and natural fibres. Many researchers have measured dimensions at multiple points, and then averaged them but again this is a highly time-consuming approach and requires a large number of observations more over the roughness of the surface creates an error in reading.

1.2.2. By Archimedes (buoyancy) principle. There are two basic situations firstly, the specimen having density higher than liquid (water) and secondly, specimen having density less than liquid (water)There are two basic test procedures for both situations [11].

1.The composite specimen having density more than water. In this, the specimen is weighed in the air then weighed when immersed in distilled water at 23°C. According to Archimedes' principle, the difference in the two weights is the weight of the water displaced by the volume of the solid [12]. Specific gravity and density are calculated as given below:

$$SG = \frac{W_a}{W_a - W_w} \qquad 1.1$$

$$Density\ of\ specimen = \frac{SG}{\rho_L} \qquad 1.2$$

where,

W_a =mass of specimen in air

W_w = mass of specimen in water

SG= specific gravity of the immersing liquid in a consistent unit

ρ_L = density of the water = 997.6 kg/m3

2. The composite specimen having density less than liquid (water). The composites having density less than water is determined by adopting some means to fully submerge it, e.g., a sinker of known mass and volume is tied with specimen with thin wire. Weighing specimen in air then weighed when immersed in distilled water at 23°C using a sinker and wire to hold the specimen completely submerged. Specific Gravity is calculated as follow:

$$SG = \frac{W_a}{W_1 - W_2} \qquad 1.3$$

where,

W_a = mass of specimen in air

W_1 = mass of specimen with sinker in air

W_2 = mass of specimen with sinker in water

SG= specific gravity of the immersing liquid in consistent unit

Density can be calculated as per equation 2.

1.2.3. Liquid pycnometry. The composite sample is inserted into the pycnometer/specific gravity bottle and weighed [13]. It will give the weight of the sample. The pycnometer is then filled with a liquid of known density generally water, in which sample is not dissolving/swelling. Weight of the empty specific gravity bottle, full of water, and full of a liquid are obtained. The difference between the weight of solvent with and without sample will give the weight of the displaced liquid and hence the specific gravity of the sample [13].

1.2.4. Helium (gas) pycnometry. In case of composites to determine the porous materials is difficult. In such type of specimen density is defined as the ratio of the mass of solid material to the sum of the volumes of the solid material blind pores within the material according to ASTM D3766[14]. The volume of such material is measured by gas displacement using the volume-pressure relationship of Boyle's Law. An inert gas such as helium is used as the displacement medium. The composite sample is sealed in a cup of a known volume. The gas is introduced in sample chamber, after placing this cup in it. The volume of this gas is measured by expanding the gas (with specimen and without specimen) into a second empty chamber of known volume. Then the volume is calculated. The ratio of the sample weight and the volume measured is a density. The density measured by Helium Pycnometry method is termed as "helium density" which means that open pores not considered in the calculation but close pores are included in the calculation [2]

1.2.5. Density gradient column. The gradient column method is used to determine the density of composites and fibres as per ISO 1183-2; ASTM D1505 [15]. It works on the principle that when two miscible liquids [16] are mixed at a control mixing rate and temperature into a tube, a uniform density gradient is formed from the top to the bottom of the tube. In this method, calibrated floats with accurately known density are requisite for reference. The density gradient ranges from the highest value at the bottom of the column to the lowest at the top. The density gradient column was developed to measure density of small samples.

Besides, above mentioned methods, there are researches where the measurement of density of the composite panels were calculated by measuring the density of the composite in air and isopropyl alcohol [17,18].

1.3 Merit and demerit of methods

In the method used by Soykeabkaew et al. [10] for density measurement using specimen dimension and mass for regularly shaped objects, assuming uniform cross-section of the material is not always correct and is time-consuming. In the case of the weighing in air method, it is widely available and most setups have precision scales but the choice of immersion liquid is still a concern [7]. Also, avoiding air bubbles is a challenge. The gas pycnometer is more expensive, requires an inert gas supply, large bulk sample size, and very soft material can be deformed but it involves less handling, easy calibrate, fast and accurate [2, 11]. The density column preparation is laborious and time-consuming. After a certain time, the gradient is disturbed. Also, to find the combination of solvent different densities and good miscibility in a specific density range is required [19]. Moreover, it requires predetermined density floats, at least three. But it offers advantages of simple construction and easy operation. It may be used to measuring several samples simultaneously and with a reasonable degree of accuracy. In this work, a simplified novel method is being attempted to measure density of irregular objects by using the Archimedes principle.

2.0 DENSITY MEASUREMENT FOR THE IRREGULAR OBJECT

The density measuring method described in this work was adopted for composites [20]. It offers an advantage of easy operation, utilizing traditionally available equipment in the common laboratory, without the requirement of a specific instrument, with high accuracy. The requirements of this method are beakers, high accuracy balance and pipette, for measuring density. This method does not require to know accurate density of liquid to be used.

2.1 Experimental procedure

In this method, a 250ml beaker is filled with a heavy liquid higher density than the specimen to be determined. Here in this work [20], the heavy liquid used is a saturated solution of Calcium Chloride whereas the light liquid used is distilled water and the temperature is kept at 30°C. Depending upon the specimen other heavy and light liquids may be used (Table 1). Then, the sample is put gently. The sample should float. After that, the liquid having lower density is added in a small increment (15-20µl) and the mixture is stirred with a glass rod till it becomes homogeneous. This is continued till the specimen is neither sink nor float. The sample may be pushed in the depth of solution to confirm that it is neither sinking nor floating i.e., sample is having neutral density as compared to solution (Figure 1 b). Normal safety precaution is to be observed depending upon the liquid [21]. Similarly, other samples are tested (Figure 1 a & c). The density of the solution is determined by the general method of Pycnometer. The density of the sample is the same as that of liquid. Five specimens for each type of composite laminate were tested and average values were considered for further discussion.

The process used in the present work can be explained using Archimedes principle [20], which states that for a body wholly or partially immersed in a fluid, the upward buoyant force acting on the body is equal to the weight of the fluid displaced by it [22]. Accordingly, reduction in weight of an object is equal to the weight of the liquid displaced by it. Considering a particular case of object sinking in liquid wholly but floating, weight of body is equal to weight of liquid having volume equal to the object which again is equal to buoyant force or upthrust exerted by the liquid on the object [5,22].

Considering Newton's second law,

$$W_s = m_s . \frac{g}{g_c} = V_s . \rho_s . \frac{g}{g_c} \quad (\because \ \rho_s = \frac{m_s}{Vs}) \qquad (1.4)$$

where,

Ws is weight of the sample

ms is mass of the object, kg

g is acceleration due to gravity m/sec2

gc is constant, kg./N.sec2

Volume displaced by sample = Vs

$$\therefore \rho_l = \frac{m_l}{V_l} = \frac{W_l/(\frac{g}{g_c})}{V_l} \qquad (1.5)$$

$$\therefore W_l = \rho_l . V_l . \frac{g}{g_c} \qquad (1.6)$$

Now, at sinking position

$$V_l = V_s \qquad (1.7)$$

$$\therefore W_l = \rho_l . Vs . \frac{g}{g_c} \qquad (1.8)$$

$$\therefore V_s . \rho_s . \frac{g}{g_c} = V_l . \rho_l . \frac{g}{g_c}$$

(as per Archimedes principle, Ws = Wl) (1.9)

$$\therefore \rho_s = \rho_l \qquad (1.10)$$

Therefore, density of specimen is equal to density of liquid displaced. That indicate that at the situation i.e., the object (specimen) sinked wholly but floating: the density of sinked specimen and liquid are same.

$$Density\ of\ specimen\ \rho_s = sp.gr\ of\ liquid\ \times \rho_w \qquad (1.11)$$

where,

ρ_w is density of water at same temperature

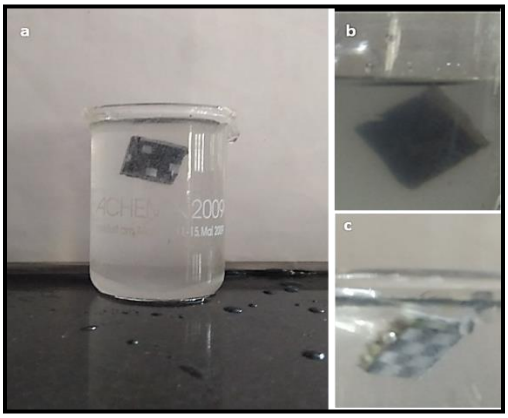

Figure 1: Density measurement

This method has its advantage over commonly used methods as error incurred in measurement of dimension of irregular shape is avoided. Here, the accurate measurement of volume is not required, as the weight of water and liquid of constant volume (volume of specific gravity bottle) is measured. The accurate density of water is known. Weight is measured accurately on high accuracy balance. It includes transparency and the density in a range of 1-5 g/cm^3 is easily controllable. It can also be used for measuring the density of hybrid composites also.

Table 1: List of heavy and light liquid for aqueous and non-aqueous solutions.

Sr. no.	Heavy liquid		Light liquid		Reference
	Solvent	Density g/cm^3	Solvent	Density g/cm^3	
Aqueous solutions					
1	Thallous Formate (saturated solution)	3.5	Water	1.00	[24]

	at 20-28°C				
2	Clerici solution at 90 °C	5.0	Water	1.00	[23]
3	Sodium bromide solution	1.49	Water	1.00	[25]
4	Calcium chloride	1.5	Water	1.00	[20]
5	Calcium nitrate	1.2065	Water	1.00	[25]
6	Sodium nitrate	1.3683	Water	1.00	[25]
7	Stannic Chloride	1.971	Water	1.00	[25]
8	Ammonium Sulphate	1.2626	Water	1.00	[25]
9	Ferric Sulphate	1.7983	Water	1.00	[25]
10	Aluminium Sulphate	1.3079	Water	1.00	[25]
Non-aqueous solution					
11	Tribromo Fluoro methane	2.7	Benzo trifluoride	1.2	[25]
12	Perchloro ethylene	1.62	Xylene	0.864	[25]
13	Tetrabromoethane	2.97	Benzene	0.876	[25]
14	Water	1.00	Methanol	0.792	[25]
15	Nitromethane	1.382	Hexane	0.659	[25]

Conclusion

The composite materials are analyzed in terms of their physical and mechanical properties to judge their sustainability. Density is one of the most influencing physical parameters on these properties that need to be measured accurately for different types of composite materials including hybrid composites. The newly adopted method, using two miscible liquids having different densities for the measurement of irregular-shaped composite density. It has the salient advantage of high accuracy by using traditionally available equipment in a common laboratory. It is, therefore, recommended this method be used to determine densities for the prediction of composite properties. The same method can also be implemented to measure the specimen other than composite having an irregular shape, small size materials like fibres, polymers, solid crystals, minerals, stones, metals, etc. provided liquids used does not affect on specimen physically or chemically

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