

Study on Effect of Angularity on Hydraulic Conductivity of Mixtures of Materials

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Abstract— The knowledge of hydraulic properties of soils such as hydraulic conductivity is very important in many physical situations such as flow in an aquifer, flow through filters in water purification, sewage treatment plant and flow in packed bed chemical reactors. It is a key parameter in diagnosing the potential for widespread groundwater contamination by pollutants, and is the basis for design of drainage and irrigation systems. The size and shape of soil particles reflect the formation history of the grains. In turn, the macro-scale behaviour of the soil mass results from particle level interactions which are affected by particle shape. Sphericity, Roundness and Smoothness characterize different scales associated to particle shape. Hence, to investigate the effect of Shape factors of sediments on hydraulic conductivity through porous media, the present study has been conducted on Constant Head Permeameter with appurtenances to measure discharge, pore pressure differences and temperature. Four number of materials such as 6.3 mm White Marble chip, 6.3 mm Crushed Quartzite, 10 mm River Washed Gravel, 16 mm Glass Spherical Glass balls and making a mixture of these above mentioned materials in fixed proportion and then conducting Hydraulic Conductivity tests on it. On the basis of experimental results a positive correlation between Permeability (K), Shape factor η (angularity) and Volume Mean diameter (dv) has been developed.

Key words: Hydraulic Conductivity, Grain Size Analysis, Angularity

I. INTRODUCTION

Information about the soil permeability is vital to the success of many geotechnical works. Various predictive equations based on Volumetric and Grain Size parameters have been proposed to estimate the permeability. Permeability is one of the most important yet variable properties in Geotechnical Engineering. Conventionally, permeability is evaluated either by In-situ or laboratory tests. In-situ tests are costly and difficult to interpret because of the complex boundary conditions involved. Laboratory tests also present formidable problems, the most troublesome being obtaining representative samples. To circumvent the testing problems, methods of estimating permeability from volumetric characteristics and grain size have previously been attempted. These predictive equations had limited success for coarser soils, and have proved to be completely unsatisfactory for fine-grained soils. The fundamental problem with these equations is that permeability is extremely sensitive to subtle changes in soil structure, a property which bulk volumetric parameters do not accurately reflect.

II. HYDRAULIC CONDUCTIVITY

Permeability (or hydraulic conductivity) refers to the ease with which water can flow through a soil. Hydraulic conductivity or permeability is the rate at which soil will transmit water under a unit hydraulic gradient. Various factors such as fluid properties, grain-size distribution, void ratio, roughness of mineral particles and degree of soil saturation affect the hydraulic conductivity. Hydraulic conductivity can be estimated by using methods based on grain size analysis or determined by the use of experimental in situ- or laboratory methods. The grain-size methods use coefficients that are estimated from empirical data, as well as some kind of representative value of the grain size. The experimental methods measure the flow in a soil material and calculate the hydraulic conductivity or transmissivity from the flow in different ways.

A key aspect of hydraulic conductivity is that a very wide range of values exist in natural soils and rocks, perhaps a range from 10^{-2} m/s (for very open gravels and cobbles) to 10^{-11} m/s (un-fissured clays or massive unfractured rock). This is a huge range – a factor of a billion! This is a much greater range than would be expected for most other geotechnical parameters such as shear strength or compressibility. It is also important to realise that the way that a fluid (such as water) passes through a soil or rock mass depends not only on the properties of the soil/rock but also on the properties of the permeating fluid. This means that a given soil or rock will behave differently if it is permeated by different fluids – for example water or hydrocarbons (oil). The problem with the term ‘permeability’, widely used in geotechnical engineering, is that in other industries (such as the oil and gas industry) it is taken to mean the ‘intrinsic permeability’ which is independent of the permeating fluid-Intrinsic permeability has the SI units of m^2 , although it is commonly described in Darcy’s (where 1 Darcy = 1×10^{-12} m^2) – and is a significantly different parameter to hydraulic conductivity.

III. EXPERIMENTAL WORK

Figure 1 shows the experimental setup

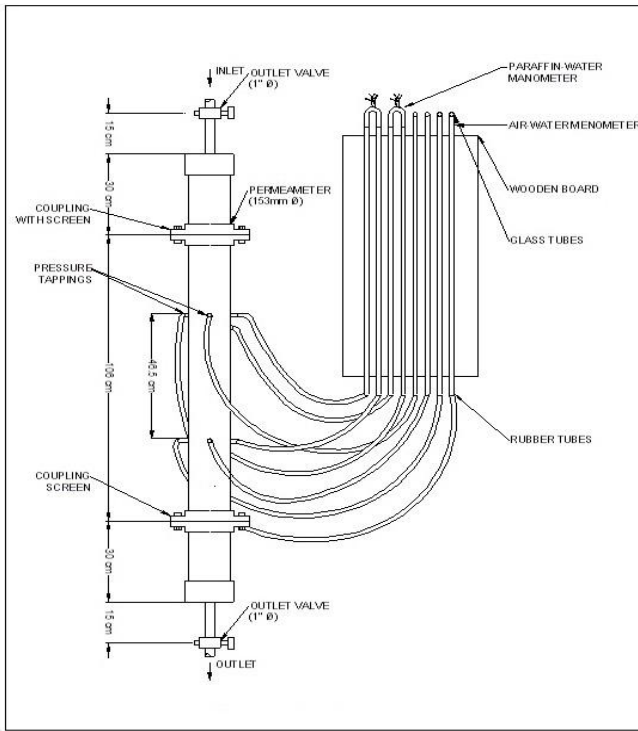


Fig. 1: Constant head permeameter

A. Experimental Equipment

The experimental equipment consists of the following items:

- 1) Permeameter
- 2) Discharge measuring device
- 3) Weighing Balance
- 4) Pycnometer
- 5) Manometer
- 6) Thermometer
- 7) Source of supply
- 8) Oven

1) Permeameter

The constant head vertical flow type permeameter was used for hydraulic tests in this work. The main permeameter section consisted of a 10.16 cm internal diameter GI tube with a total length of 1.06 m and a test length of 46.5 cm.

2) Discharge measurement

The discharge was measured by volumetric method. The water was collected in a bucket for a certain period, which was recorded with a stopwatch and collected water was then measured with the help of a 2000 cc capacity glass jar. Volume of water collected at a particular duration will give the discharge.

3) Weighing balance

Electronic weighing balance were used for measuring the weight during specific gravity test

4) Pycnometer

I.S. pycnometer is used in the specific gravity test.

S. no	Sieve size(mm)	Weight of sieve	Weight of sieve+ aggregates	Weight retained(gm)	% Weight retained	Cumulative % weight retained	% Finer
1	8	650	913.25	263.25	5.27	5.27	94.74
2	6.3	890	3927.79	3037.79	60.76	66.02	33.98
3	5.6	720	878.34	158.34	3.17	69.19	30.81
4	4.75	680	782.85	102.85	2.06	71.24	28.76
5	4	700	1898.34	1198.34	23.97	95.21	4.79
6	pan	650	889.43	239.43	4.79	100.00	0.00

Table 1: Sieve Analysis for White marble chip

5) Manometer

To cover the desired range of flow, two types of manometer were used:

- 1) Air-water manometer
- 2) Paraffin water manometer

6) Thermometer

I.S. Mercury Thermometer measuring temp from 0°C to 80°C was used for measuring the temperature of water.

7) Source of supply

The permeameter receives its water supply from an overhead tank at a height of 2.65 m above the permeameter outlet. The tank receives its supply from a recirculating tank so that a constant head is maintained in the overhead tank.

8) Oven

Oven was used to dry out the soil samples collected from different boreholes before performing the sieve analysis.

B. Materials Used

The various materials used in the present study have been listed below:

- 1) Marble Chips: 6.3mm uniform sizes were used.
- 2) Crushed Quartzite: 6.3 mm uniform sizes were used
- 3) River washed Gravel: 10 mm uniform sizes were used.
- 4) Spherical Glass balls: 16 mm uniform sizes were used.
- 5) Mixtures of Marble chips, Crushed Quartzite, River washed gravel, and Spherical glass balls in fixed proportions were used

IV. EXPERIMENTAL PROCEDURE

The various tests and procedure conducted during the course of this study have been illustrated below .

A. Sieve Analysis Test

The various materials used in the present investigation are of different sizes and shapes. The materials were sieved according to IS: from bulk material in order to obtain the similar shape for each size, although it is not sure that the shape of separate grain be identical. The Sieves analysis for white marble chip performed in this study have been tabulated in Table 1-6. To ensure the proper sieving 10 minutes were allowed to shake the material in each case so that uniform size material is allowed to pass through one sieve and retained in another sieve. After this material was weighted from each sieve and after calculation work percentage finer was plotted against grain size on semi log graph paper, as shown in Fig 2. From the grain-size distribution curves, diameters of soil particles at 10%, 30%, 50% & 60% cumulative weight were determined, and the coefficients of uniformity (C_u), and Coefficient of Curvature (C_c) were calculated.

Parameters	Values
d60	7.56
d50	7.36
d30	4.99
d10	4.12
Cu	1.8
Cc	0.8

Table 2: Different parameters obtained from S- Curve



Figure 1: Grain size distribution curve for White Marble Chip

S. no	Sieve size(mm)	Weight of sieve	Weight of sieve+ aggregates	Weight retained(gm)	% Weight retained	Cumulative % weight retained	% Finer
1	8	650	889.9	239.9	4.80	4.80	95.20
2	6.3	890	3892.72	3030	60.60	65.40	34.60
3	5.6	720	891.68	171.68	3.43	68.83	31.17
4	4.75	680	800.43	120.43	2.41	71.24	28.76
5	4	700	1798.04	1098.04	21.96	93.20	6.80
6	3.35	650	978.38	328.38	6.57	99.77	0.23
	pan	690	701.57	11.57	0.2314	100	0

Table 3: Sieve Analysis for Crushed Quartzite Sample

Parameters	Values
d60	7.4
d50	7.11
d30	5.42
d10	3.86
Cu	1.91
Cc	1.03

Table 4: Different parameters obtained from S- Curve

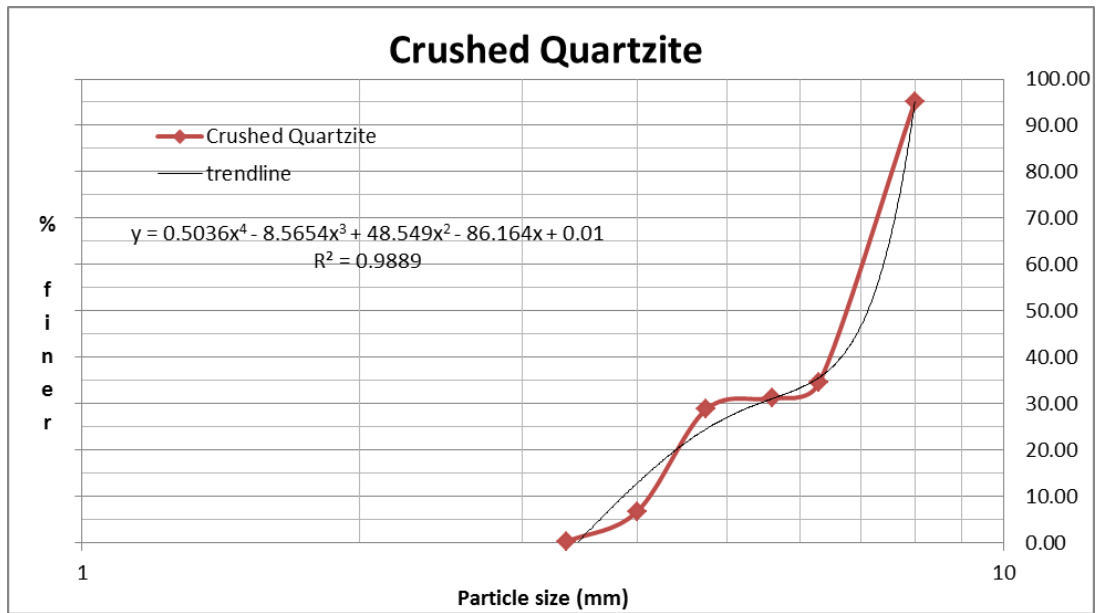


Figure 2: Grain size distribution curve for Crushed Quartzite

S. no	Sieve size(mm)	Weight of sieve	Weight of sieve+ aggregates	Weight retained(gm)	% Weight retained	Cumulative % weight retained	% Finer
1	12.5	850	980.43	130.43	2.56	2.56	97.44
2	10	810	4248.54	3438.54	67.42	69.98	30.02
3	8	650	1675.87	1025.87	20.12	90.09	9.91
4	6.3	890	970.33	80.33	1.58	91.67	8.33
5	5.6	720	854.87	134.87	2.64	94.31	5.69
6	4.75	680	799.67	230	4.51	98.82	1.18
7	pan	690	749.96	59.96	1.18	100.00	0.00

Table 5: Sieve Analysis for River Washed Gravel

Parameters	Values
d60	11.48
d50	11.11
d30	10.09
d10	7.67
Cu	1.5
Cc	1.16

Table 6: Different parameters obtained from S- Curve

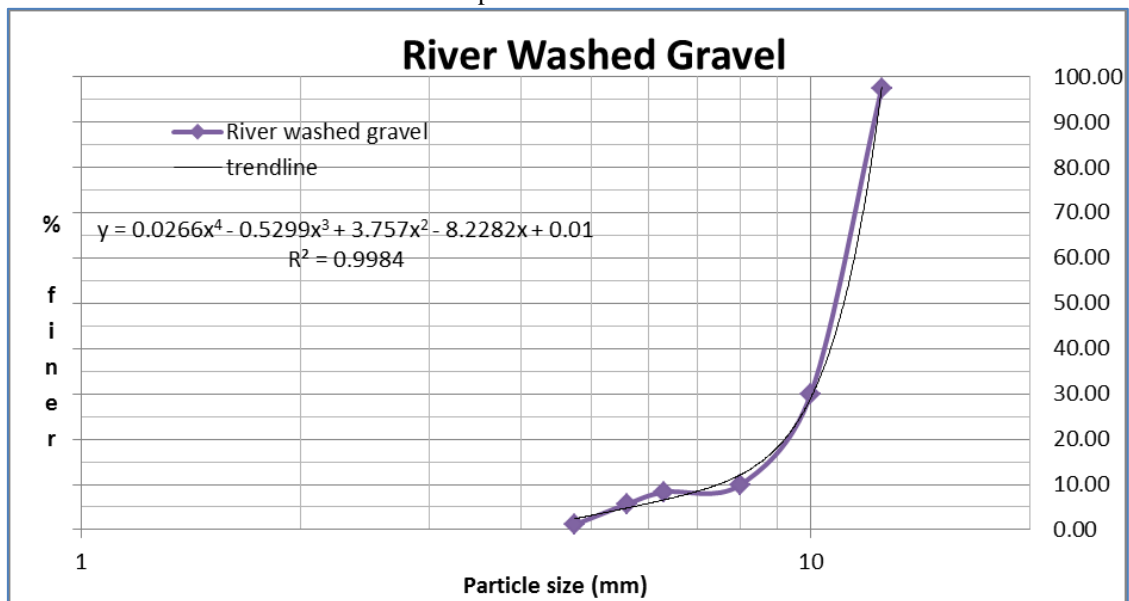


Figure 3: Grain size distribution curve for River Washed Gravel

B. Angularity Tests

The size of the angular materials used in the present investigation was 0.3 mm minimum to 1.6 cm maximum. The size of the cylinder used was 15.0 cm in diameter and 30.5 cm deep. This size fulfilled the requirement that $D/d_g \sim 8.0$. As Recommended by B.S.0812:1967.(Here D is the diameter of the cylinder and d_g is the geometric mean size of the material.)

All tests were performed in accordance with B.S. 812:1967. The aggregates in the cylinder shall then be weighed to the accuracy of one place of decimal after gram using electronic weighing balance.

$$\text{Angularity } (\eta) = 100 \left(1 - \frac{W_c}{W_w G_s} \right)$$

Sample no.	Weight of Aggregates in cylinder Wc(gm)	Weight of water required to fill the cylinder Ww(gm)	Specific Gravity G	% voids η %	Angularity no. A.N
1	8280	5310	2.54	38.68	6
2	8301	5310	2.54	38.53	6
3	8267	5310	2.54	38.78	6

Table 7: Angularity test for 6.3 mm White Marble Chip

C. Hydraulic Tests

The hydraulic tests were conducted to study the effect of resistance to flow of water in a given sample of material. The method of carrying out these tests are as follows.

Preparation of the Bed: Before filling the permeameter with the material to be tested, the inlet portion of the permeameter was taken off. It was proposed in the present study to keep the porosity constant for all runs of the materials. Therefore, the weight of the material needed to fill the permeameter was calculated as:-

$$W_s = (1-n) V_T G_s \gamma_w$$

Where,

W_s is weight of the material, n is porosity, V_T is volume of the tube, G_s is specific gravity of the material, γ_w is specific weight of the water

TEST RUN: This involved three main operations

- 1) Measuring the discharge through the permeameter.
- 2) Reading the pressure drop across the test length of the material.
- 3) Reading the temperature of water

In all the runs, observations were taken in receding order of magnitude of discharge and hydraulic gradient. The test was started with maximum discharge so that if there was any settlement of the bed due to the impact of the jet of incoming water, it was secured in the beginning. The bed was then checked at the end of each run for settlement, if any. The porosity of the bed was determined after making due allowances for settlement. The discharge was measured by collecting the water in a bucket for a certain period, which was recorded with a stopwatch. The flow was then reduced for the next observation of the run. This operation was continued till the discharge was decreased from maximum to a certain measurable minimum discharge.

V. ANALYSIS OF RESULT

The present study focuses on investigating and developing a relationship between the Hydraulic conductivity, mean diameter and angularity of the materials used. .

Angularity number (A.N.) = percentage voids – 33
Or, A.N. = $\eta - 33$

where,

η = porosity or percentage voids when the material is compacted in a standard manner prescribed by B.S. 812:1967

W_c = weight of the aggregate in the cylinder

W_w = weight of the water required to fill the cylinder

G_s = specific gravity of the aggregates

The % voids & Angularity number obtained for different sizes & different proportion of 6.3mm White Marble chip is tabulated in table 7.

A. Relationship between Angularity and Size of Particles

As already discussed in chapter 2 and chapter 3, the angularity of the particles can be used as a measure of the Shape factor of the particles. The angularity number tests were, therefore, conducted on the various materials. The angularity of any material depends on its size. In order to investigate the relationship between the angularity of any material (defined as the percentage voids in a material when it is compacted in standard manner prescribed by B.S. 812:1967) and its size, the experimental data of angularity number tests were analysed.

From a study of these results, it is seen that the angularity of any material decreases with an increases in the size. These results are plotted using log of angularity ($\log \eta$) against the corresponding log of geometric mean diameter ($\log d_v$) of the material. All the data appear to follow a straight- line law given by:

$$\log \eta = \bar{n} \log d_v + \log C' \tag{1}$$

Eq. (1) can be simplified as:

$$\eta = C' d_v^{\bar{n}} \tag{2}$$

The value of index \bar{n} in this equation was found to be constant at - 2.54547 for all the materials from The value of C varies with the shape of particles. The value of C, for various materials are obtained.

The Eq. (2) can be written as:

$$C' = \eta d_v^{2.54} \tag{3}$$

where,

C' = parameter defining the angularity and depends on shape of the particle.

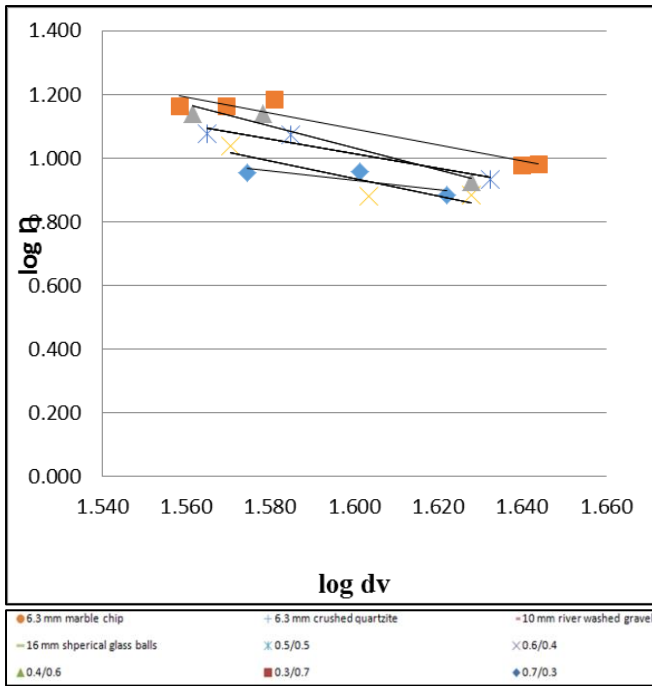


Fig. 4: Curve of log η v/s log dv

B. Relationship between Permeability and Angularity Granular Material

The results of experimental investigation for white marble chips used can therefore be plotted on log-log graph as Friction factor vs Reynolds number as shown in Fig. 5. . The variation was found to follow a straight line which shows that the flow is in linear regime. These results follow an equation of the form:

$$Fr = \frac{C_1}{Re} \tag{4}$$

$$\text{Or } \frac{2gidv}{V^2} = \frac{C_1}{\frac{\rho Vdv}{\mu}}$$

As per Darcy Law,

$$V = Ki$$

Putting this value ,we get

$$\frac{Kv}{dv^2} = \frac{2g}{C_1} = C \tag{5}$$

where,

Material:	White Marble Chip		Size of Material (dv):	0.6875 cm						
Weight of Material(Ws) :	13.1kg		Temperature of fluid :	25° C						
Porosity (Π) :	38.66%		Test Length (L):	46.5 cm						
Specific Gravity (Gs) :	2.543		Area of permeameter (Ap):	81.03 cm ²						
Size of Permeameter (D):	10.16 cm		Kinematic viscosity (v):	8.85 × 10 ⁻³ cm ² /sec						
S.NO.	Q	V	Vs	H	i	Re	Fr	Fr _{40%}	K	Kp
	(cm ³ /sec)	(cm/sec)	(cm/sec)	(cm)	(H/L)	(V* ρ v/ μ)	(2*i*g*dv)/V ²	Corrected at 40%	(cm/sec)	(cm/sec)
1	132.98	1.64	4.24	10.80	0.23	127.49	116.32	100.50	7.07	18.28
2	140.29	1.73	4.48	14.00	0.30	134.50	135.48	117.06	5.75	14.87
3	149.39	1.84	4.77	15.10	0.32	143.22	128.87	111.34	5.68	14.68
4	157.47	1.94	5.03	16.50	0.35	150.97	126.74	109.50	5.48	14.17
5	165.01	2.04	5.27	18.30	0.39	158.20	128.01	110.60	5.17	13.38
6	169.45	2.09	5.41	20.10	0.43	162.45	133.33	115.20	4.84	12.51

Table 8: Hydraulic conductivity for 6.3 mm White Marble chip

- C₁ = constant for given porosity depends only on the shape of particle
- C = parameter defining the permeability of the material
- N = kinematic viscosity of fluid
- d_v = volume mean diameter of particles.
- K = coefficient of permeability (hydraulic conductivity)

Others parameters were same as mentioned earlier.

Similarly, factor C in Eq. (5), which defines the permeability of material is also dependent on shape only provided that the porosity and other factors are constant. Therefore, we can write that, C' is a function of C.

Mathematically, this can be expressed as:

$$C' = F(C) \tag{6}$$

To obtain the required porosity of 40% in each case, it was found necessary to compact the material with a heavy rammer, which could have crushed the material. No attempt was therefore made to compact the material with a heavy rammer to get the proposed porosity. The tests had been conducted at different suitable porosity for each material.

All the points in appear to follow the straight-line law given by:

$$\text{Log } C' = \text{log } B + m \text{ log } C \tag{7}$$

Eq. (6) can be simplified as :

$$C' = B C^m \tag{8}$$

The value of B and m in the above equation are obtained. The final equation can be written as:

$$C' = 54075.43 C^{3.067} \tag{7}$$

or,

$$C^{-3.067} = \frac{54075.43}{C'} \tag{8}$$

Putting the value of C and C' respectively, the above equation can be expressed as:

$$\left[\frac{K}{dv^2} \right]^{-3.067} = \frac{54075.43}{\Pi dv^{2.54}}$$

$$K = \frac{0.0286}{\Pi^{-0.326} dv^{0.214}} \tag{9}$$

where,

- K = coefficient of permeability (cm/s)
- dv = Volume mean diameter of particles (cm)
- Π = Angularity of the particles (%)

From the above equation, it is obvious that by conducting Angularity number tests and Volume Mean Diameter test & Hydraulic Conductivity test, an idea about the permeability of a given material can be obtained.

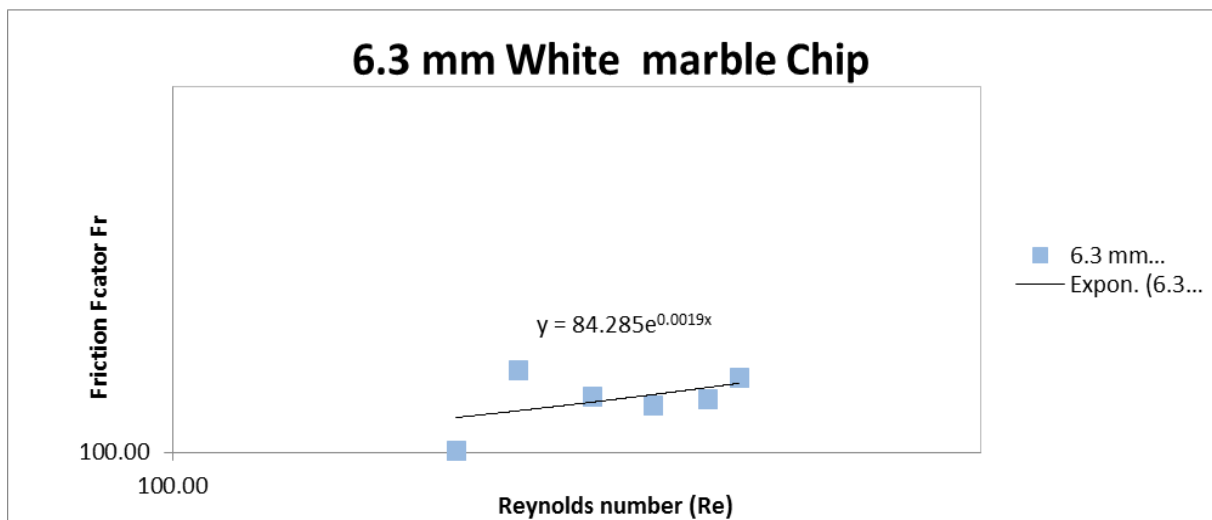


Fig. 5: Curve of Friction factor v/s Reynolds number for 6.3 mm Marble chip

VI. CONCLUSIONS

From the discussion related to analysis of results, an important conclusion drawn on the basis of this study reflects that Hydraulic resistance decreases as the porosity increase thus increasing the hydraulic conductivity. On the basis of experimental results, the relationship between K , d_v and η of the materials are as under:

$$K = \frac{0.0286}{\eta^{-0.326} d_v^{0.214}}$$

This equation is applicable for the different shape particles at a porosity of 40% and temperature 25^o C. The plots of Friction factor and Reynold's number on log-log scale shows a linear variation at low Reynold's number and deviates in curvilinear form at higher Reynold's number, for different materials used. The seepage velocity increases resulting in an increase in Reynold's number. In the present work a systematic experimental investigation is carried out to explore the relationship between the angularity and the size of particles for a given shape. It is found that the relationship between the angularity and size of particles follows the law:

$$\eta = C'd_v$$

η is found to be same for all the shapes studied but C' changes with the shape of the material. Hence, it is concluded that C' depends upon the shape of the particle. It is seen that the angularity of any material decreases with increase in its size.

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