INFLUENCE OF ORIENTATION AND SIZE OF VOIDS ON CONCRETE CUBE STRENGTH

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ABSTRACT

Many concrete units like hollow concrete blocks; columns and beams are used as construction components without adequate knowledge of the effect of void orientation. Void orientation causes variation in the thickness of the concrete components. Consequently, influence of square voids inclined at 0^0,15^0, 25°, 35°, 45° to the horizontal axis of as-cast face of hollow concrete cubes were investigated.

Analysis of the four grades of concrete studied showed that both void orientation and size of voids have influence on the uniaxial compressive strength of hollow concrete cubes. It showed that 45° void orientation has the highest strength. Void size effect depicts a minimum value corresponding to the least effective bearing area. It is recommended that for void volumes up to 30%, 45° void orientation should be used because of its high strength value.

1. INTRODUCTION

Concrete is the dominant structural element in buildings in Nigeria and the high cost of concrete making dictates the need to make optional use of the functional characteristics of concrete elements.

Furthermore, geometrical shapes may also be used as in the case of castellated steel beams and columns, to optimize structural property with a saving in material quantity and cost. Voids may be incorporated in precast concrete blocks to produce cellular blocks [1]. The incorporation of the voids:

1. Reduces the quantity of materials,
2. Improves the insulation property,
3. Improves the acoustic property,
4. Reduces self-weight and
5. Reduces moisture migration.

In hollow concrete production, the vertical axis of the void is not always perpendicular to the base of the concrete element. Similarly, the orientation of the boundaries of the void with respect to the sides of the element could vary. Consequently, the void may be inclined to the plane of the as-cast face, thereby altering the centroidal position. This in turn causes variation in thickness and seriously influences the stress distribution when the hollow concrete product is subjected to axial load. (See figure 1).

The current practice of making the void perpendicular to the as-cast face may not be the optimum position. In this work on hollow sandcrete cubes, Okonkwo [2] found that void 45° orientation have high strength values.

Strength calculation for hollow concrete units has been based on the gross area rather than on the net area, which actually bears and transmits the load. This has been the specification in some national codes of practice, like NIS-75 [3], BS 2028 [4] and ASTM C90-75 [5]. However Uzoamaka [6], Scheider et al [7] and Curtain et al [8] criticized the above method of computing the compressive strength and upheld that the compressive strength should be determined on the basis of the net area, since it is the solid area of the hollow block that actually bears and transmits the load. Therefore, strength calculation should be based on net area.

Ezeokonkwo [9] and Eze-Uzoamaka et al [10] have shown that the relationship between the effective strength and the center-web to end-web ratio when the as-cast side of hollow sandcrete block is the bearing face at test, can be used to determine the limit to which the bearing face can be reduced so that the load carrying capacity of the hollow sandcrete block is not reduced.
In view of the foregoing observations, it becomes necessary to investigate the influence of void volume orientation on the compressive strength of hollow cubes.

2. TEST DETAILS
2.1 Specimen Preparation

The size of the hollow concrete cube was 150mm x 150mm x 150mm. The volumes of the square voids are 10%, 15%, 20% and '25% expressed as a percentage of the specimen volume. Wooden plates were used to form the required void size and inclined at a desired angle of 0^0, 15^0, 25^0, 35^0, 45^0. The modulus were well oiled to enhance demoulding which was done, twenty-four (24) hours after casting.

The influence of the orientation and volume of the voids on the following concrete grades: 15N/mm^2, 20N/mm^2, 25N/mm^2 and 30N/mm^2 were investigated. The required proportion of cement, fine aggregate, coarse aggregate and water to produce the desired strength were obtained from concrete mix design. The mix proportions for 1.0 m^3 of concrete are as shown in Table 1.

Uncrushed coarse aggregate obtained from Eziana in Nsukka local government area of Enugu State of Nigeria. It is a reddish-brown irregular gravel with a rough structure texture It can be seen from Table 2 and Figs. 2 - 5 that void orientation has influence on the uniaxial compressive strength of hollow concrete cubes based on net area. A worst orientation is apparent. Analysis showed that 25% of the 35^0 orientation results have compressive strength less than that of 0^0 orientation; 43.75% of the 25^0 orientation results have strength less than that of 0^0 orientation; and 56.25% of 15^0 orientation results have strength less than that of 0^0 orientation. In all, at orientation less than 25^0, the probability that the strength of a hollow concrete cube is less than the strength of 0^0 orientation is very high.

The test result indicates that 45^0 orientations has the highest strength values rather than the traditional 0^0 orientation. However, formation of the orientation creates a production problem. No square void greater than 30% of the specimen volume can successfully fit into the specimen at and moisture content of 0.93%. Opi River sand was used in this study. It has a high specific surface and belongs to zone 3 [11]. The specimen were cured in a curing tank at ambient temperature in the laboratory and tested at 28 - day strength. A total of 240 hollow concrete cubes were prepared, of which 12 were control cubes, 3 each for the various concrete grades used.

2.2 Testing
The Dension Compression Testing Machine Model T.I.A./M.C was used for the compression test of the hollow concrete cubes and the control specimens. The as-cast face was the bearing surface at test. To produce an even and smooth surface, the procedure of rubbing down the test face with carboradum plate was employed.

3. RESULTS

Based on the configuration of the hollow concrete cubes, only the net area strength was calculated. The summary of the results is given in Table 2.

4. DISCUSSION OF TEST RESULTS

4.1. Effect of Void Orientation

45^0 orientation. It follows that a void volume above 30% of the specimen volume, 0° orientation remains the best position. However, care should be taken to avoid slight inclination, as there is 56.25% chance of obtaining strength less than the 0^0 orientation value.

4.2. Effect of void Volume

The influence of void volume on the strength is also shown in table 1. For the various concrete grades 0^0 and 45^0 void orientations showed continuous decrease in strength as the void volume increased except for concrete grade $20N/mm^2$. It may be argued that other factors such as water/cement ratio, climatic conditions, workmanship, testing techniques and rate of loading may have contributed to the reduction in the strength of concrete. This may have been responsible for the observed trend. At 25% void volume, the four grades: $15N/mm^2$, $20N/mm^2$, *25N/mm*^{2} and *30N/mm*^{2} examined have their strength reduced to 53.27%, 61.63 %, 58.12% and 57.64% respectively.

Also 15°, 25° and 35° orientation showed non-continuous decrease in the strength of various concrete grades as void size increases. But the probability that at various orientations, that larger void size will cause maximum reduction in the strength of any concrete grade is about 50%.

The reduction in strength of hollow concrete cubes as a result of void orientation and void volume is least with the 45° orientation irrespective of concrete grade. Compressive strength drops by up to 50% for void volumes of up to 10% in some of the concrete grades, but further increase in void volume seems to make negligible additional reduction in strength. Figs 6 - 9 show that the effect of void volume on strength is non-linear in nature.

This trend can be linked to the influence of small sizes on the strength of specimens, and is only associated with the net area bearing strengths. This is because as the void volume increases, the aggregating solid elements of a hollow concrete cube become small. It has been observed that the strength of smaller specimens is on the average larger than that of the larger specimen [12]

CONCLUSIONS

The following conclusions can be drawn from the study:

1. The void orientation effect on strength has no defined trend. In all, at a void orientation of less than 25°, the probability that the strength of a hollow concrete cube is less than-the corresponding strength of a cube with its hollow at 0° orientation is very high.

2. The result also indicates that the highest strength values are obtained when the hollow is at 45° orientation. Such orientation is only possible for voids less than 30% of the specimen volume.

3. There is a parabolic relationship between void volume and net strength of hollow

concrete cubes.

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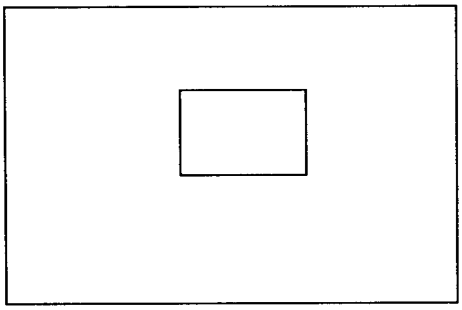
Table 1: Mix proportions for the various grades of concrete.

Concrete grades *(N/mm^2)*	Constituents (kg)			
	Cement	Water	Fine	Coarse
15	290	180	686	1219
20	321	180	656	1218
25	346	180	629	1220
30	387	180	577	1229

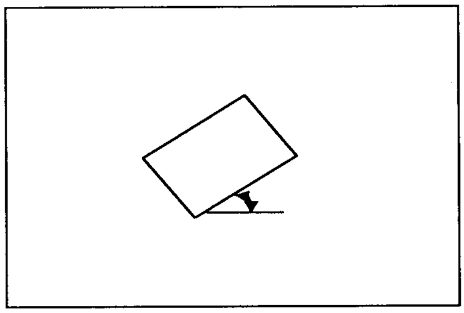
2 Table 2: Details of Test Results

Strength grade $15/mm^2$

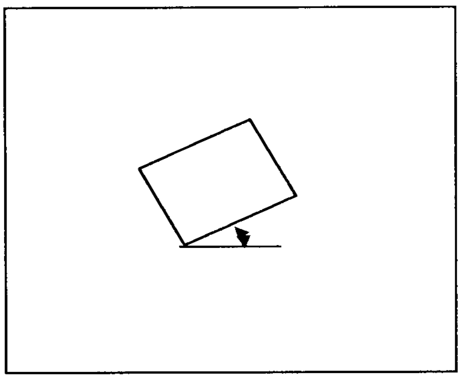
Rotation (^{0}) Void Volume(%)	0^0	15^0	25^0	35^0	45^0
0	16.013	16.013	16.013	16.013	16.013
10	14.436	11.480	11.973	12.950	16.567
15	12.850	12.503	9.553	11.807	14.763
20	11.437	11.070	11.623	13.100	14.760
25	7.483	7.680	10.630	14.367	13.770
Strength grade *$20N/mm^2$*					
0	31.293	31.293	31.293	31.293	31.293
10	18.327	14.107	18.863	20.993	22.140
15	12.327	13.197	13.547	15.457	16.150
20	11.437	12.730	10.333	13.100	15.870
25	12.007	12.597	12.203	14.367	16.727
Strength grade *$25N/mm^2$*					
0	30.550	30.550	30.550	30.550	30.550
10	15.090	12.957	13.450	14.597	15.583
15	14.937	14.937	13.023	13.200	16.150
20	12.913	12.917	13.100	12.913	14.210
25	12.793	8.860	13.580	13.383	14.170
Strength grade *$30N/mm^2$*					
0	28.343	28.343	28.343	28.343	28.343
10	14.417	13.123	15.090	16.893	20.340
15	15.803	11.113	13.547	16.843	18.580
20	15.503	12.176	12.730	18.560	19.257
25	12.007	13.186	14.170	12.203	15.547



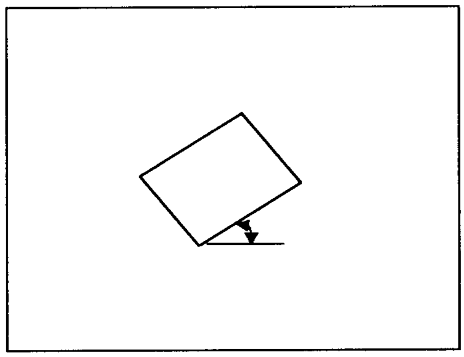
0^0 Orientation



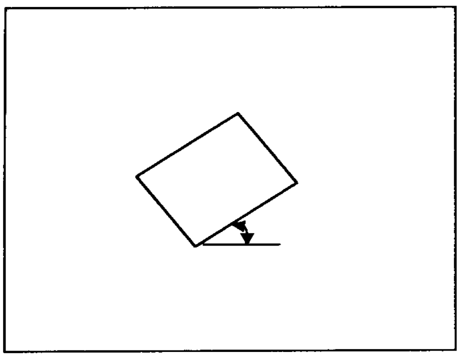
15^0 orientation



25^0 Orientation

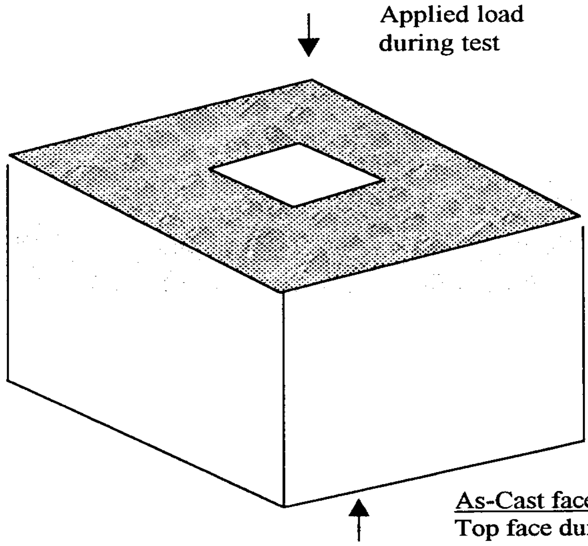


35^0 Orientation



45 Orientation

Fig. 1 Angles of orientation



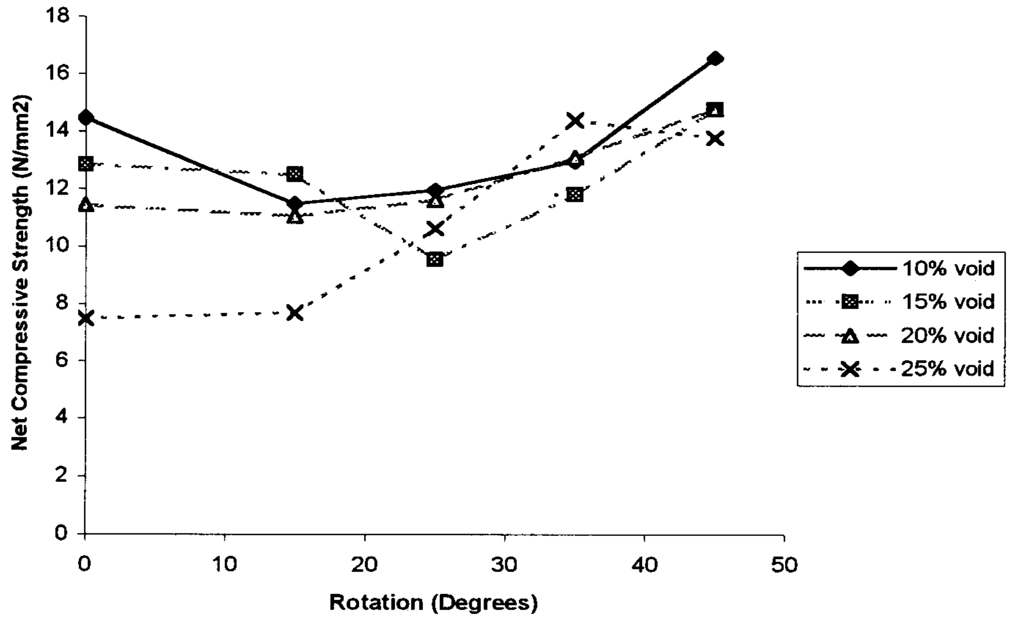


Fig. 2 Variation of Void Orientation with Strength

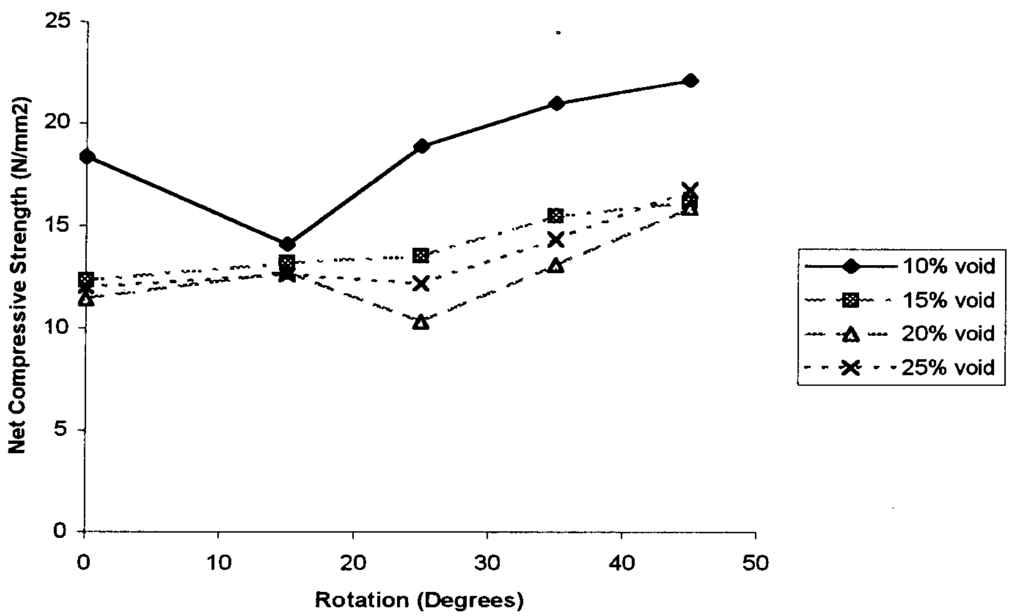


Fig. 3 Variation of Void Orientation with Strength

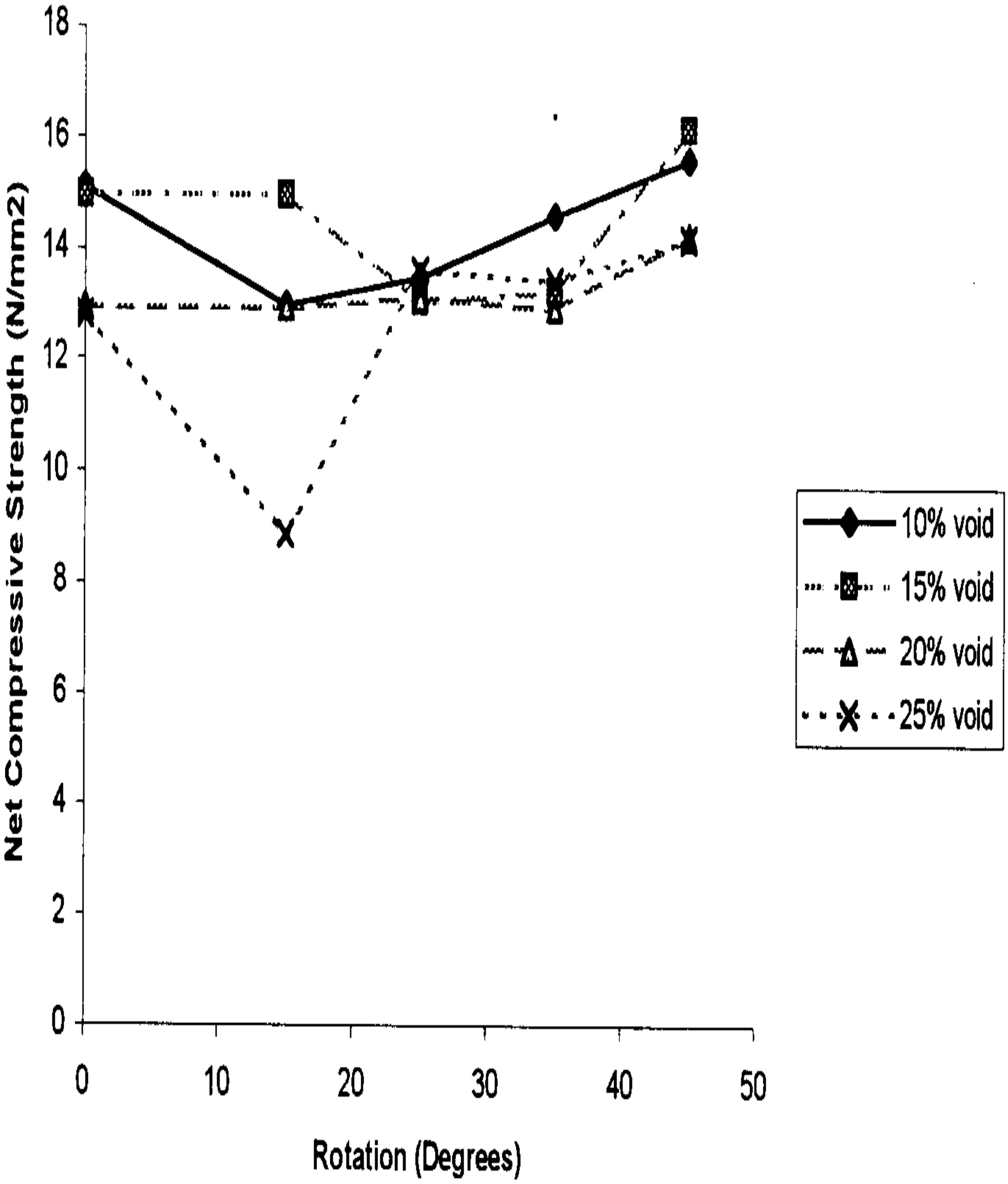


Fig. 4 Variation of Void Orientation with Strength

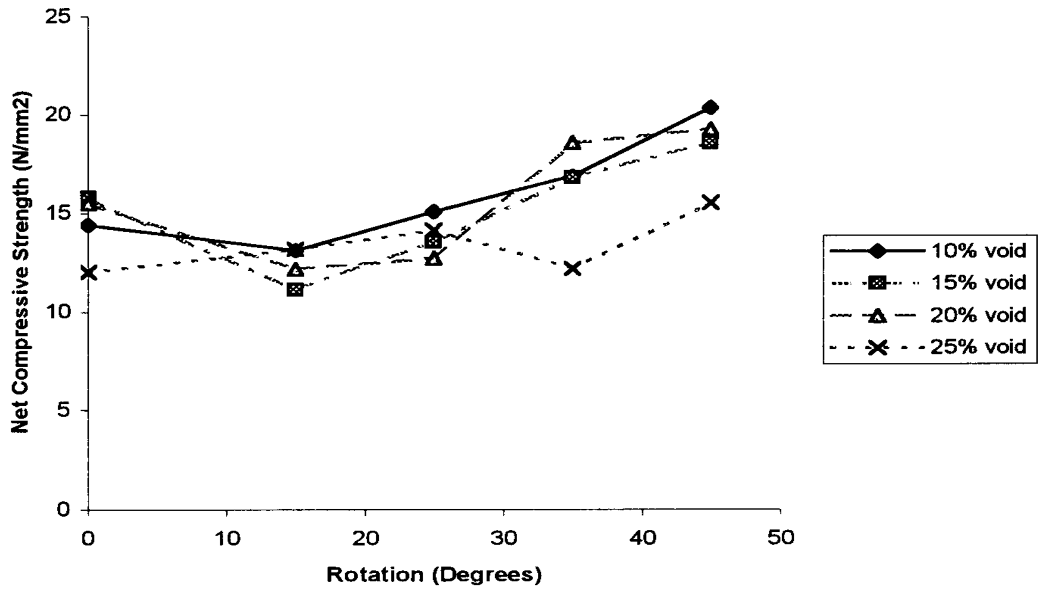


Fig. 5 Variation of Void Orientation with Strength

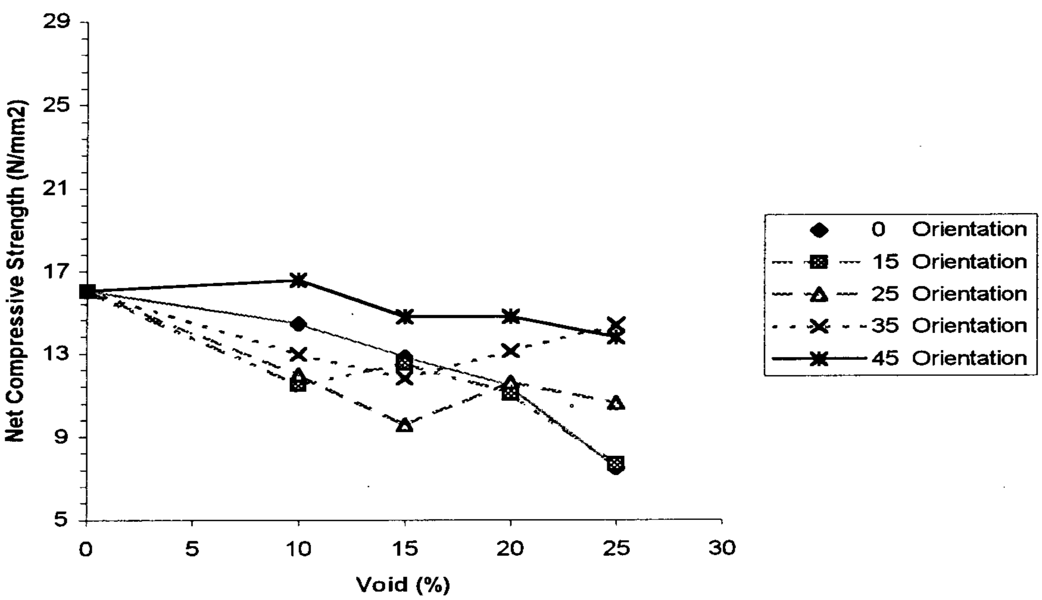


Fig. 6 Variation of Void Volume with Strength

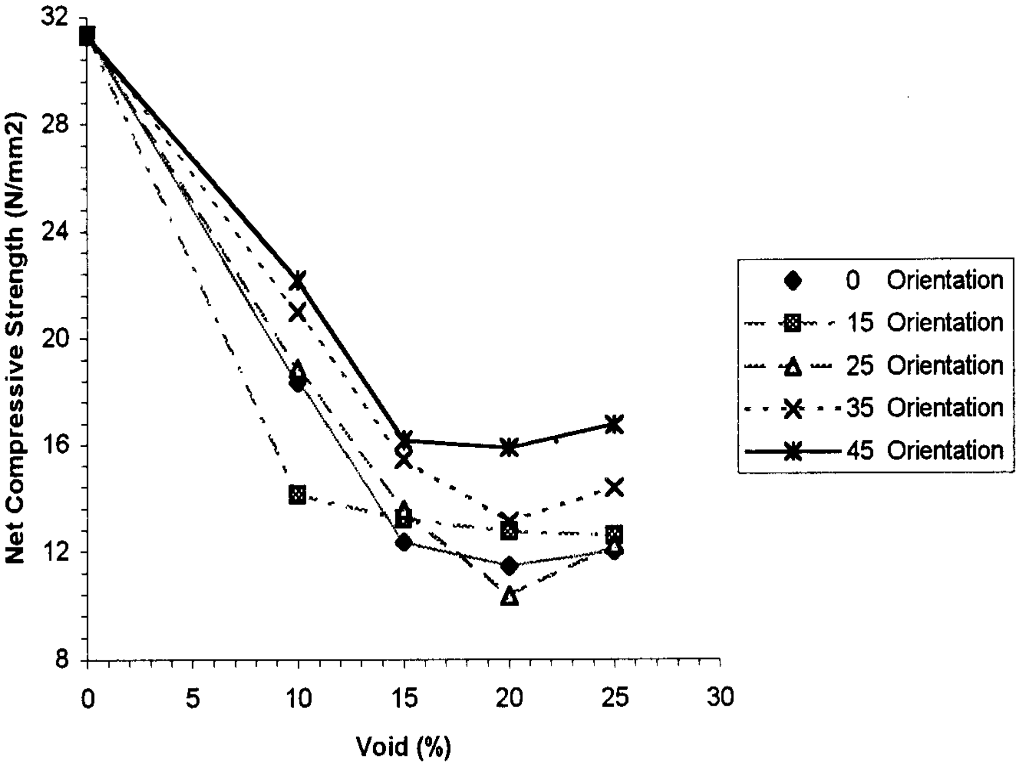


Fig. 7 Variation of Void Volume with Strength

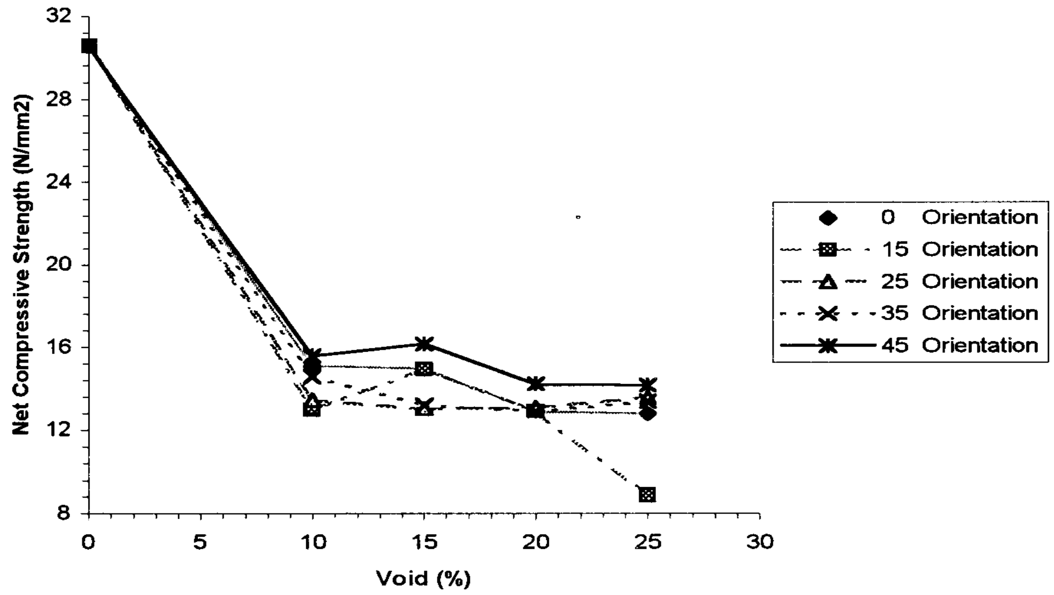


Fig 8 Variation of Void Volume with Strength

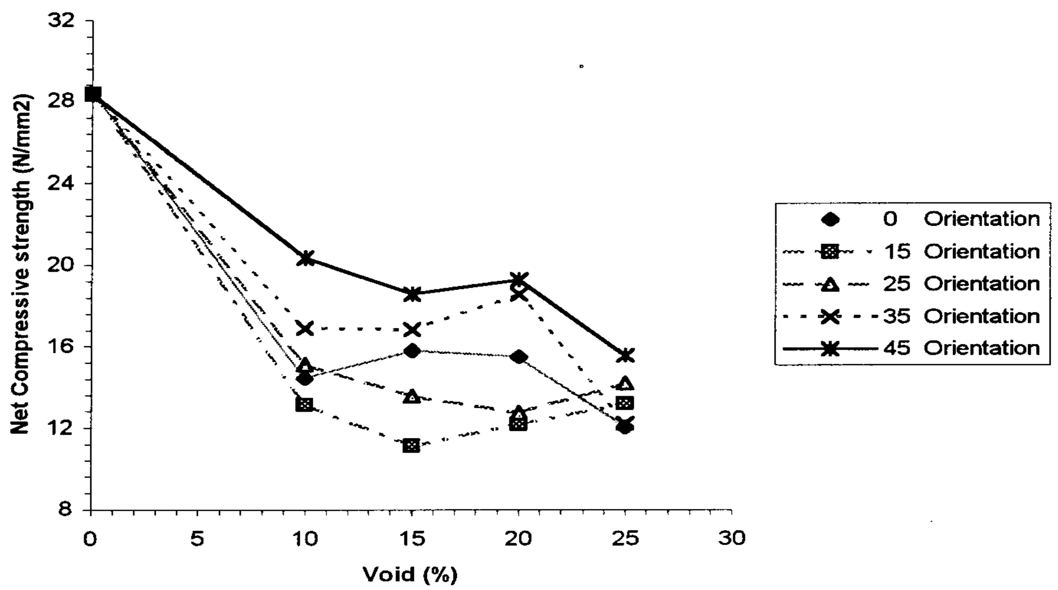


Fig. 9 Variation of Void Volume with Strength