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THE EFFECT OF POROSITY ON ENGINEERING PROPERTIES OF VESICULAR AMYGDALOIDAL BASALTS

P.S.K.Murthy, Sachin Gupta, Dhirendra Kumar, Mahabir Dixit
Scientist
Central Soil and Materials Research Station, New Delhi

***Abstract*—The interconnection of vesicles in basaltic flows greatly affects the engineering properties such as uniaxial compressive strength, modulus of elasticity, Poisson's ratio, tensile strength and sonic velocities. Sometimes these vesicles are filled with secondary minerals such as quartz/olivine/calcite form as amygdules (which are impermeable). In the present study, to understand effect of porosity, vesicular and amygdular basaltic flows collected from central and west-central India were investigated for these engineering properties and correlated with apparent porosity of core samples. It is observed that a good level of correlation is obtained for uniaxial compressive strength (UCS), elastic modulus (E) and Poisson's ratio in vesicular basalts when porosity >8-10%. In case of Brazilian strengths a linearly downward trend is observed with the increase in porosity values. And, no significant correlation is observed for waves' velocities in both variants of basalts.**

Keywords—apparent porosity, strength properties, uniaxial compressive strength, vesicular basalt, amygdular basalt.

I. INTRODUCTION

The engineering behaviour of any civil engineering structure largely depends on the strength and deformation properties of geo-materials existing in the foundation or vicinity of structures. In the case of basaltic flows due to the presence of non-connected vesicles or amygdules (filled with secondary minerals such as quartz, calcite, olivine etc.) the investigation of the representative engineering properties is a tough task. The porosity of these rocks is a prime determining factor in obtaining representative strength parameters [1,2,3]. Hence, in the present study, apparent porosity (as a measure of interconnected pores) has been used to understand the effect on engineering properties such as uniaxial compressive strength, modulus of elasticity, Poisson's ratio, tensile strength and sonic velocities (compressive and shear).

Several researchers observed the strength of vesicles in basaltic flows is considerably effected by their porosity [3,5,6,8,9,10]. And, several relationships and correlations have been established between the porosity and engineering properties of different rock types [3,12,13]. Al-Harthi et al. [2] studied on vesicular basalts using porosity values obtain from Image analysis of rock core samples. They showedexcellent correlation between (R=0.99) the porosity values from Image analysis and from the calculated porosity from the Eq. (1).Where, n is apparent porosity, e is void ratio obtained by Eq. (2).

$$n = e/1+e \qquad (1)$$

$$e = (G\gamma_w - \gamma_{dry}) - 1 \qquad (2)$$

G is apparent specific gravity of the material, γ_w is the unit weight of water in g/cm^3 , γ_{dry} is the dry density of the sample in g/cm^3. Hence, in the present research, porosity is calculated from regular shaped rock core samples using the equations (1) & (2). Here, density is measured by weight and volume of rock cores and specific gravity (G) is obtained by density bottle method on powered rock sample [4].

To understand the influence of porosity on engineering properties, the basaltic variants were collected from central and west-central India and the investigations were carried out in saturated condition as per ISRM suggested methods [11]. Also, the mineralogical compositions of both vesicular and amygdaloidal basalts are quantified through X-ray diffraction (XRD) analysis [7], the average mineralogical composition of basalts is determined.

II. MINERALOGICAL COMPOSITION

Table-1 Average chemical composition

Mineral	VB(%)	AB(%)
Augite	27.1	26.5
Albite	38.4	36.2
Olivine	2.0	12.2
Labradorite	23.6	17.6
Quartz	Not Detected	4.5
Magnetite	Not Detected	Not Detected
Illite	6.5	2.5
Montmorillonite	2.4	0.5

Figure 1 shows X-ray diffraction patterns [7] of average powered samples of vesicular and amygdaloidal basalts (counts v/s 2-THETA). Here, Cukα radiation (λ = 1.5404A°) is used for generating diffraction patterns. Table 1 shows average mineralogical composition of these basalts.

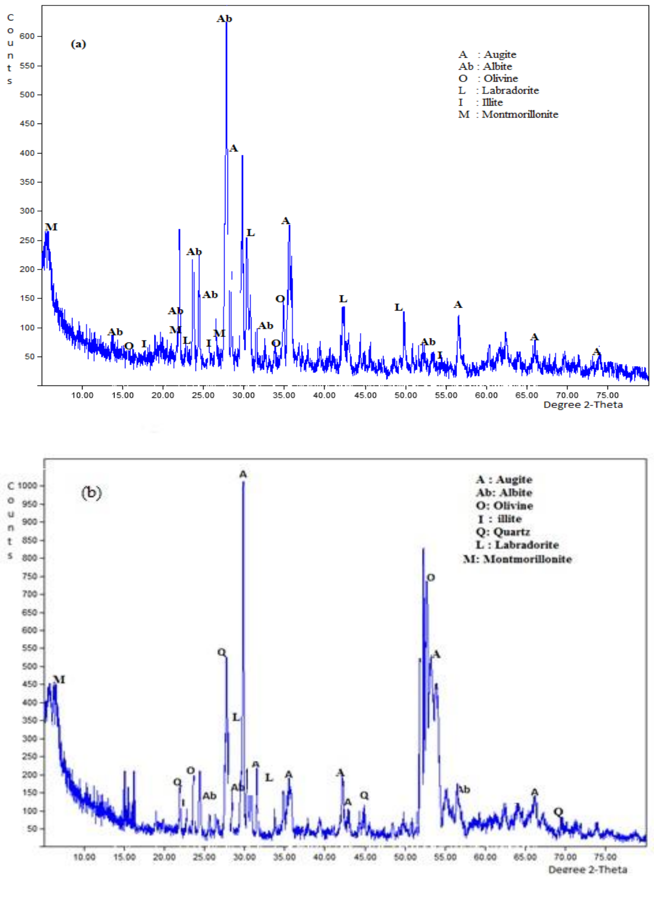

Fig.1 X-ray diffraction patterns for (a) Vesicular basalt (VB) (b) Amygdaloidal basalt (AB)

III. RESULTS AND DISCUSSION

All the investigations were carried out in saturated condition duly applying the procedures suggested by International Society of Rock Mechanics [11]. The samples were vacuum saturated in water and applying a vacuum not less than 800Pa for 1 hour. The uniaxial compressive strength (UCS) was evaluated for NX size cylindrical cores with length to diameter ratio of 2.5. Under statically applied compressive load the elastic modulus and Poisson's ratio is obtained.The Indirect Tensile Strength was assessed employing Brazilian test, the NX size saturated specimens, with length to diameter ratio of 0.5, under static load. In Brazilian test, the loading is compressive. But, the failure takes place under tension because of the experimental fact that most of rocks in biaxial stress fields fail in tension at their uniaxial tensile strength when one principal stress is tensile and the other finite principal stress is compressive with a magnitude not exceeding three times that of the tensile principal stress.For all the samples tested in uniaxial compression, waves' velocities were evaluated-namely, compression wave velocity and shear wave velocity. These were evaluated by employing two piezoelectric crystals of 200 kHz and 33 kHz frequency for compression and shear wave respectively.

A.Apparent Porosity

The apparent porosities of both variants of basalt using equations (1) & (2) have been calculated. Where unit weight of water is taken as 1 g/cc; and specific gravity of the vesicular and amygdaloidal basaltic samples are 2.6 and 2.7 respectively. The investigation reveals that higher coefficient of variation in porosities for vesicular basalts (4-14%) against amygdular basalts (2-8%).

B.Correlation between Apparent Porosity and UCS_{sat}

It is observed that UCS for saturated samples (UCS_{sat}) in vesicular basalts varied from 20to 40MPa where as in amygdaloidal basalt it is varied from 40 to 90MPa. It shows that the secondary mineral fillings with olivine and calcite in amygdular basalt improve in much more compact rock and that has resulted in higher strengths than the vesicular basalt.

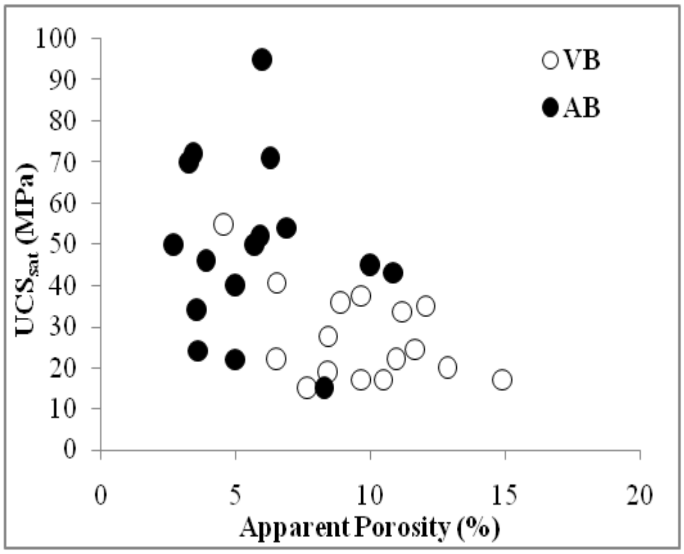

Fig.2 Influence of Porosity on UCSsat

Figure 2 shows that vesicular basalt samples an exponential decrease in relation with porosity. Moreover, the decrease is substantial up to 8.5 % porosity after that it became gradual. Turgrul and Gurpinar [12] have obtained the similar relationship for other variants of basalts. In the case of amygdular basalts, there is no correlation exists between UCS and porosity; there by suggesting that for UCS, organization of vesicles is more crucial than its interconnectivity.

C. Correlation between Apparent Porosity and E_{sat}

Both horizontal and vertical strains are measured through data acquisition system and the same are used to calculate elastic modulus and Poisson's ratio under uniaxial compression. From figure 3 it is observed that the variation of E_{sat} in amygdular basalts is higher for the samples having lower porosity. In the case of vesicular basalts there is no significant effect of porosity on elastic modulus is observed when porosity ranges from 6 to 14%.

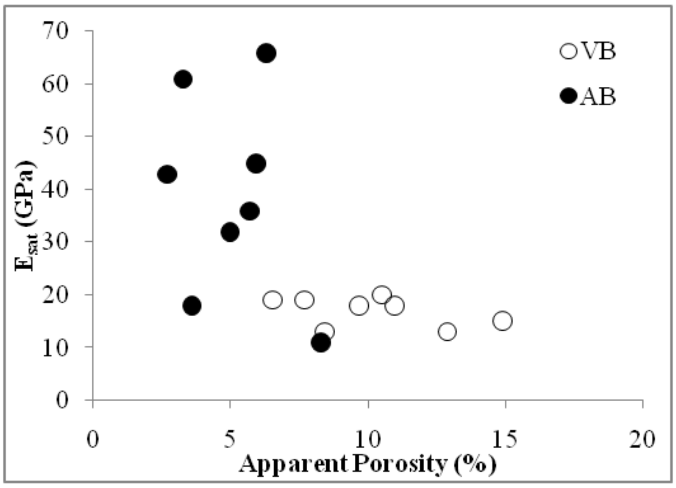

Fig.3 Influence of Porosity on Esat

D. Correlation between Apparent Porosity and μ_{sat}
Figure 4 shows the variation of Poisson's ratio (μ_{sat}) with apparent porosity for both VB and AB variants. It is observed that the range of variation of μ_{sat} is similar for both VB and AB variants.

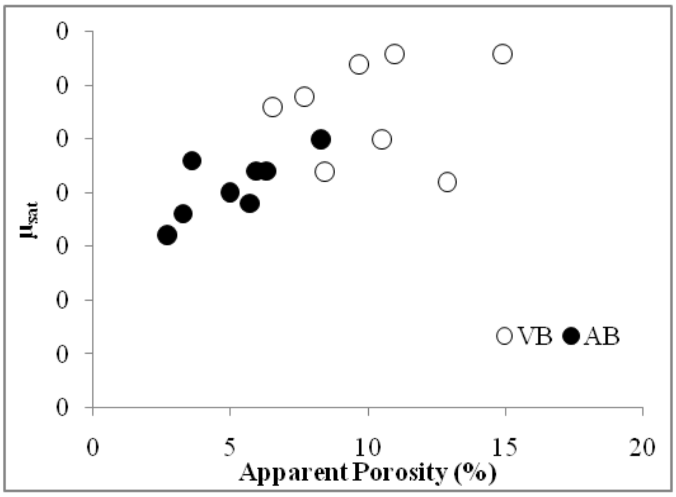

Fig.4 Influence of Porosity on μ_{sat}

Generally, Poisson's ratio is increased as the porosity is increased and becomes more or less constant for porosity values >10%. It is inferred that at porosity > 10%, the effect of pore spaces on Poisson's ratio is dominated by rock material and become more or less constant values. The data presented by Yale and Nieto [14] have shown similar relationship with Poisson's ratio and become constant at porosity values>10%.

E. Correlation between Apparent Porosity and σt_{sat}
Similar to UCS, the indirect tensile strength (σt_{sat}) of both variants inversely related to porosity. Neglecting few, clear linear trend exist (R=0.77) with porosity in both variants of basalt (Figure 5).

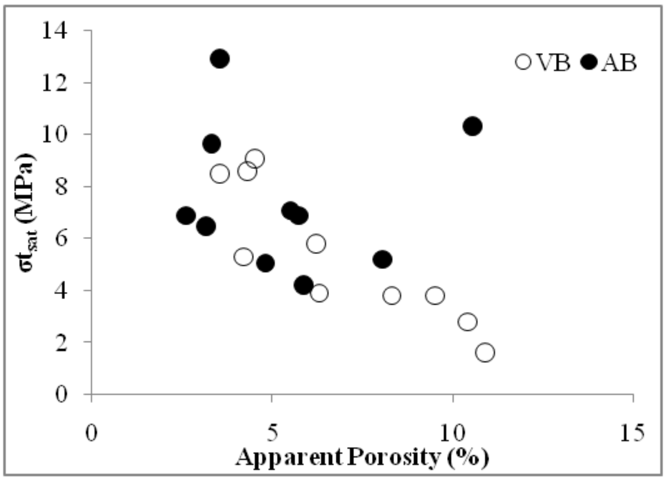

Fig.5 Influence of Porosity on σt_{sat}

F. Correlation between Waves' velocities
It is observed from the results that the waves' velocities data for VB are much similar to AB. It is inferred that the reduction in velocities of both VB and AB is possibly due to alteration of clay mineral fillings on water saturation. To meet the present objective, effect of porosity on compressive wave velocity (Vp) and shear wave velocity (Vs) on saturated samples of both variants of basalts is observed.

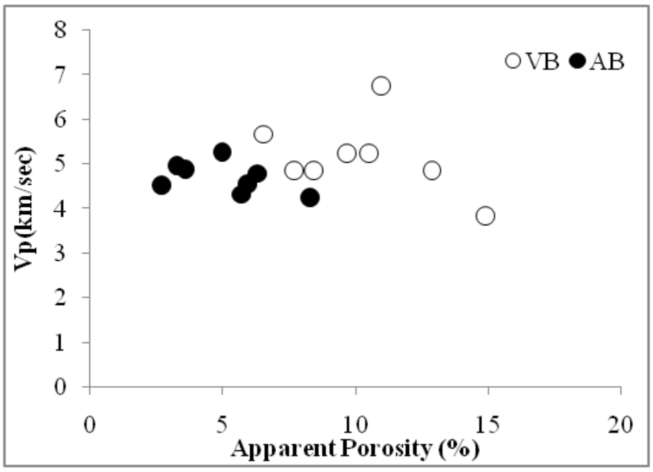

Fig.6 Influence of Porosity on Vp-sat

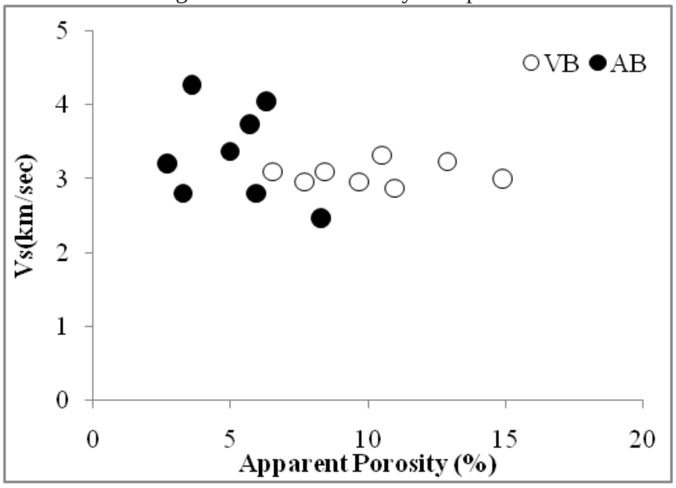

Fig.7 Influence of Porosity on Vs-sat

Figure 6 and 7 shows that there is no significant effect of porosity on waves' velocities in both variants of basalts. It is inferred that the nominal size of pores and core sample dia. has no significant effect on dynamic properties as they do with static properties and uniaxial compressive strength.

IV. CONCLUSION

The objective of the paper is to show the effect of porosity on various geotechnical properties used for the design of engineering projects. Using apparent porosity, a better correlation is pronounced for UCS, elastic modulus and Poisson's ratio in vesicular basalts with good confidence. It is observed that the effect becomes insignificant and sometimes gradual when porosity of vesicular basalts increased beyond 8-10%. Due to formation of amygdules, the porosity decreases which result in higher strengths than VB. However, Brazilian strengths in both variants have shown a linear downward trend with the porosity. In case of waves velocities, no significant effect of porosity is observed in both variants of basalts.

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