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Influence of Natural Pozzolan on Porosity-Cementitious Materials Ratio in Controlling the Strength of Cement Treated Recycled Base Pavement Mixtures

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Abstract:- The objective of this research project is to explore the influence of the amount of natural pozzolan (trass) as a partial replacement of Portland cement on the strength characteristic (q_u) of Cement Treated Recycled Base (CTRB) pavement mixtures. As parameters controlling the unconfined compressive strength, the porosity, curing time and the porosity to cementitious materials ratio were investigated in relation to the maximum influence of natural pozzolan contents in various mix designs. Based on the statistical analysis, the results showed good correlations between unconfined compressive strength and cementitious materials content (cement and trass) and porosity of the CTRB mixture. The increase in Unconfined Compressive Strength (UCS) of the CTRB also depended on the increase in curing time of the CTRB samples. The results also revealed that the void to cementitious materials ratio ($\boldsymbol{\eta/c_{iv}}$) is a good indicator of the UCS of the CTRB mixtures. This research project proposes some empirical models to estimate the efficiency factor $\boldsymbol{\alpha}$ using the equivalent cementitious material content concept of the mixture proportion. Strength prediction of the CTRB mixtures using this proposed efficiency factor $\boldsymbol{\alpha}$ was reviewed using Feret’s equation for concrete material.

Keywords:- CTRB, Compressive strength, Natural pozzolan, Porosity, Porosity to cementitious materials ratio.

I. INTRODUCTION

Cement Treated Recycled Base (CTRB) material in pavement application is a well-established practice and is applied frequently in pavement rehabilitation and reconstruction recycling techniques. Pavement rehabilitation techniques usually generate large quantities of Reclaimed Asphalt Pavement (RAP) and granular base materials aggregate that are suitable for recycling (Guthrie et al., 2007). However, inadequate strength and stiffness characteristics along with end product variability limit their applications in pavement construction; therefore, a cementitious material to improve the physical properties of the RAP and granular base materials is required to overcome the limitations(Guthrie et al 2007). Some technical issues in the use of cement as a cementitious material are related to shrinkage, cracking, and durability, which cause accelerated materials degradation and premature pavement failure (Guthrie et al., 2002). As the bonds develop, the hydration products experience a volume change and the pavement shrinks, causing autogenous shrinkage cracks (Scullion et al., 2000).Therefore, there is a need to explore other materials to achieve greater volumetric stability of the end products employed in pavement applications.

Natural pozzolans such as fly ash, silica fume, and slag are characterized as Supplementary Cementing Materials (SCMs) with cementitious properties and are increasingly being used in concrete and cement mixtures due to their engineering properties, and also for economical and environmental reasons (Mehta, 1998). Jongpradist et al.(2010) confirmed the potential and efficacy of adding ground disposed (aged) pozzolanic material (fly ash) into cement-clay mixtures.

The unconfined compressive strength test was indicated as the most representative test to determinethe strength of soil-cement and cement treated RAP mixes. According to Consoli et al. (2011), a mixture proportion methodology based on index porosity to cement ratio showed a fundamental role in the assessment of the target strength of clayey soil-cement mixtures. According to Jongpradist et al. (2010), the equivalent cementitious content concept A_w^* in conjunction with the efficiency factor $\boldsymbol{\alpha}$ can be successfully implemented to predict the strength of clay-cement-fly ash mixtures. Since there are no previous research studies that have proposed mathematical models to predict the strength of CTRB containing SCMs, this research project initiates an investigation of the strength characteristic of CTRB mixtures using two RAP and granular base aggregate mix ratios. Parameters that may influence the strength characteristic and that can reproduce the influence of natural pozzolan in an empirical model using the efficiency factor($\boldsymbol{\alpha}$) were investigated. A mix proportion procedure, based on the use of the porosity index to cementitious ratio ($\boldsymbol{\eta/c_{iv}^*}$) in conjunction with $\boldsymbol{\alpha}$, was explored in this study.

II. EXPERIMENTAL METHOD AND MATERIALS

The experimental program in this study was performed in three parts. First, the physical, chemical and mechanical properties of the materials in CTRB were reviewed and investigated. Second, the optimum moisture content (OMC) and maximum dry density (MDD) of the mixtures were determined in the lab. Third,the Unconfined Compressive Strength (UCS) tests were performed after sample conditioning in the lab. The next sections in this paper describe the three parts of this study in more detail.

2.1. RAP, Aggregate Base Materials, and Cement

The RAP aggregate material included in this experimental study was collected from the cold-milled Hot-Mixed Asphalt surface course pavement materials in the M.T. Haryono highway in Jakarta and the Dawuan-Cikampek rural road section in West Java, while the granular base materials were collected from base course pavement material stockpiles in Palimanan-Cidangpinggan, Cirebon, and Dawuan-Cikampek in West Java. Table 1 shows the physical properties of both the RAP and the aggregate base materials, including their sieve size analysis and grain-size distribution in Figure 1. Based on a unique specification for CTRB and CTRSB (Bina Marga, 2006),the maximum aggregate sizeis 1.5 inches. In this experiment, the percent passing no.40 and no.200 sieves were 15%-30% and 5%-12%, respectively, in accordance with the AASHTO 1972 guidelines for cement stabilized soil. According to the AASHTO soil classification procedure and the Unified Soil Classification System (USCS) designation, these two RAP and aggregate base materials mixtures (40% RAP : 60% aggregate base and 60% RAP : 40% aggregate base) were designated as non-plastic soil and classified as A-1-a and Well-Graded Gravel (GW), respectively.

The Portland cement used in this experiment was Type I Portland cement with a specific gravity (Gs) of 3.14. The designated design cement contents in the mixtures were 2%, 4% and 6% by weight and were partially replaced with natural pozzolan as shown in Table 3.

Table 1. Physical Properties of RAP and Aggregate Base Materials

		Aggregate Base				RAP				
		DAWUAN		CIREBON		DAWUAN		M.T. HARYON		
		Fin	Coar	Fin	Coar	Fin	Coa	Fin	Coar	
2.	Apparent Specific	2.79	2.73	2.57	2.58	2.63	2.74	2.56	2.62	SNI 03-1969-1990
3.	Effective Specific	2.75	2.63	2.43	2.40	2.55	2.66	2.51	2.54	SNI 03-1969-1990
4.	Apparent Specific Gravity (mix)	40% RAP : 60% RAM							2.58	
		60% RAP : 40% RAM							2.64	
5.	Water	1.1	2.70	4.7	6.25	2.2	2.37	1.3	2.63	SNI 03-1970-
6.	Sieve Analysis	See Figure 1.								SNI 03-1968-
7.	Plasticity Index	NP		NP		-		-		SNI 03-1966-

2.2. Natural Pozzolan (Trass)

The natural pozzolan (trass) used as an addition to cementitious mixtures in this experimental study was from Manado, North Sulawesi, Indonesia. It was predominantly aged volcanic ash and was considered to be potentially useful as a Supplementary Cementing Material (SCM) when combined with Portland cement.

The natural pozzolan (trass) in this study was air dried in open areas approximately 1-2 days to reduce the moisture content to approximately 0.5%. After drying, the pozzolan was sieved passing sieve size no. 200 and was mechanically ground until more than 95% of the particles passed sieve size no. 325 by weight to increase the specific surface area for hydration. Table 2 shows the grain-size distribution and other properties of the trass. Grinding the porous, coarse trass particles reduced both the porosity and the particle size of the trass so it was similar in particle size to fly ash (Paya et al., 1997).

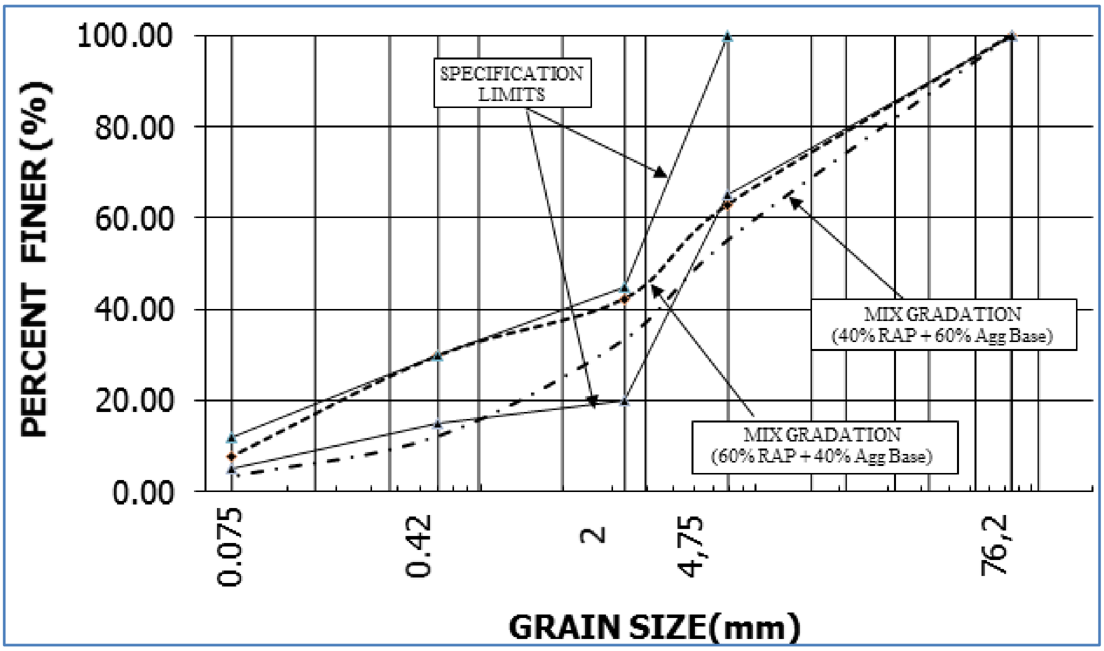

Figure 1. Grain-size Distribution of RAP and Aggregate Base Materials

Table 2. Physical and Mechanical Properties of Natural Pozzolan (Trass)

GRADATION	# No. 200	100% passing
	# No. 325	99% passing
Gs	2,42	
SAI	79% (7 days)	85% (28 days)

Table 3.Unconfined Compressive Strength Test Summary

RAP :Agg Base (%)	C_{iv}(%) Cement Content	T_w(%) Trass Content	Curing Time (days)
40 : 60	2; 4; 6 (by weight of total RAP and aggregate base material)	0; 15; 30 (by weight of cement)	7; 14; 28
60 : 40			

2.3. Compaction Tests

Compaction of the CTRB samples was in accordance to the modified proctor testing procedure in conjunction with the Indonesian Standard for Compaction, SNI 03-1742-1990, which is similar to the ASTM D1557 (Standard Test Method for Laboratory Compaction Characteristic of Soil Using Modified Effort, Method C). The size of the sample cylindrical mold was 4x4.58 inches. The RAP and aggregate base materials were air dried for 48 hours to remove any remaining moisture. The samples from this test were also used to determine the OMC and MDD of the CTRB mixtures.

2.4. Unconfined Compressive Strength Tests

The main effort of this research project was concentrated in evaluating the influence of the cementitious materials content, curing time period, porosity,and void to cementitious materials ratio on the strength of the two CTRB mixtures (containing 40% RAP and 60% RAP). The applied testing procedure was in accordance with the Indonesian standard for UCS testing, SNI 03-1974-1990, which is similar to ASTM Standard C109C/109M-08 (ASTM 2008a). The UCS tests were conducted at samples aged of 6,13, and 27 days after submerging the samples for one day in plain water. The reported strength test results are averages of three companion samples.

III. RESULTS AND DISCUSSION

3.1. Effect of Cementitious Material on Physical Properties of CTRB Specimens

The results in Table 4 show that the OMC of the 40% RAP CTRB mixture was higher than that of the 60% RAP CTRB mixture. The greater the RAP content in the sample mix, the more the particles coated with asphalt, resulting in less water absorption by the materials. The MDD of the 60% RAP CTRB mixture was higher than that of the 40% CTRB; this phenomenon is due to the higher asphalt content in the 60% RAP CTRB mixture, which acts as a lubricant that influences the mixture to become denser during compaction of the samples. In addition, the gradation of the 60% RAP CTRB mixture was finer than that of the 40% RAP CTRB mixture.

In summary, the finer the materials the denser the compacted samples.The results also showed that as the cementitious materials (cement + trass) content was increased in each mixture, the OMC values tended to slightly increase for the two CTRB mixtures as well as the MDD values (γ_d) for the 60% RAP CTRB, but not for the 40% RAP CTRB MDD values (γ_d). This trend reveals that the 60% RAP CTRB mixture had consistently higher γ_d than the 40% RAP CTRB mixture.

Table 4. OMC and MDD of the 40% RAP : 60% Aggregate Base and 60% RAP : 40% Aggregate Base Mixtures

Mixes	Cement : Trass	40% RAP : 60% RAM		60% RAP : 40% RAM	
		OMC	MDD	OMC	MDD
A1	2% : 0%	9,80	1,96	9,23	1,98
B1	4% : 0%	8,50	1,96	8,88	2,01
C1	6% : 0%	8,30	1,98	8,25	2,08
A2	85%A_1:15%A_1	9,50	1,95	9,08	2,01
B2	85%B_1:15%B_1	9,30	1,97	8,74	2,02
C2	85%C_1:15%C_1	8,80	1,99	8,49	2,04
A3	70%A_1:30%A_1	9,60	1,95	9,28	2,00
B3	70%B_1:30%B_1	9,10	1,96	8,78	2,05
C3	70%C_1:30%C_1	9,00	1,97	8,70	2,09

Due to the differences in materials in the CTRB samples, the specific gravities varied based on mixture proportions. For the 40% RAP and 60% aggregate base CTRB, the specific gravity Gs_s was 2.575, while for the 60% RAP and 40% aggregate base CTRB the specific gravity Gs_s was 2.64. The specific gravities of the Portland cement and trass held constant at a Gs_c of 3.14 and 2.42, respectively. Since the porosity of the CTRB samples is a function of the specific gravity values of RAP, aggregate base materials (Gs_s), cement (Gs_c), and trass (Gs_t), the porosity can be calculated from Eq. (1). This equation is a modification of the porosity equation for cement-treated soils by Consoli et al. (2011). In this equation, the porosity values of the CTRB samples were calculated by assuming that the trass in the mixtures influenced the porosity of the samples.

$$\boldsymbol{\eta} = \mathbf{100} - \mathbf{100}\left[\left(\frac{\frac{\gamma_d V_s}{\frac{100}{100}+\frac{C}{100}+\frac{Tw}{100}} X \frac{100}{100}}{Gs_s}\right) + \left(\frac{\frac{\gamma_d V_s}{\frac{100}{100}+\frac{C}{100}+\frac{Tw}{100}} X \frac{C}{100}}{Gs_c}\right) + \left(\frac{\frac{\gamma_d V_s}{\frac{100}{100}+\frac{C}{100}+\frac{Tw}{100}} X \frac{Tw}{100}}{Gs_t}\right)\right] \Big/ V_S \quad \ldots$$

(1)

3.2. Efficiency Factor (α)

Due to the presence of pozzolanic materials in the mixtures through cement addition or replacement, the efficiency factor **α** of the trass is the function of both the grain-size distribution and chemical composition of the pozzolanic materials (Papadakis and Tsimas, 2002). The strength prediction was not based on the influence of cement content in the mix but on the equivalent cementitious material content and the influence of the efficiency factor of trass. Equation (2) shows the equivalent cementitious materials content formula including the efficiency factor of trass.

$\mathbf{C_{iv}^{*} = C_{iv} + \alpha T_w}$ .... (2)

Where C_{iv} is the Portland cement content (%), T_w is trass content (%) and **α** is the efficiency factor of trass for addition or replacement of Portland cement.

Since the influence of each mixing component on CTRB strength is similar to that of concrete, it was reasonable to assume that empirical equations developed in concrete research were also applicable to the strength prediction of the CTRB mixture. In calculating the value of **α** for each mix proportion based on strength evaluation, Feret's equation, modified by Papadakis and Tsimas (2002) in Equation (3), was applied.

$$\mathbf{f'_{(c)}} = \mathbf{K}\left[\frac{\mathbf{1}}{\mathbf{W}/_{(\mathbf{c_{iv}}+\,\boldsymbol{\alpha}\mathbf{Tw})}} - \mathbf{a}\right] \quad (3)$$

However, before obtaining the value of α, other parameters in Eq. (3) had to be calculated. **K** and **a** parameters must first be calculated by assuming a mixture without a pozzolanic material. Once all the parameters were calculated and reviewed, the relationship between unconfined compressive strength (UCS) and cement-water ratio (C_{iv}/W) was formulated as shown in Figure 3. The **K** values for curing time, 7, 14 and 28 days, were calculated from the slopes of the graphs in Figure 3. The parameter **a** in Equation (3) was back-calculated from the testing results. The values of parameters **K** and **a** are presented in Table 5. The efficiency factors **α** of each mixture were then calculated by substituting the measured UCS and mixing components into Eq. (3) using the predetermined **K** and **a** values for each curing period. The equation to calculate the efficiency factor **α** is as follows:

$$\boldsymbol{\alpha} = \frac{\left\{\left[\frac{\mathbf{f'_{(c)}}}{\mathbf{K}}+\mathbf{a}\right].\mathbf{W}\right\}-\mathbf{c_{iv}}}{\mathbf{Fw}} \quad (4)$$

Based on the observation of **α** values and the mixture proportions, it was found that **α** for the 40% RAP CTRB tended to increase with an increase in water content. Conversely, **α** tended to decrease when the cementitious materials (cement + trass) content increased. For the 60% RAP CTRB mixture, the **α** value tended to increase with the increase in cement content, and conversely, **α** tended to decrease with the increase in water and trass contents.

Based on the results, for the 40% RAP CTRB, it is reasonable to characterize the **α** value based on the ratio of the mixture components W/(C_{iv} + F_w), and C_{iv}/(W + F_w) of the 60% RAP CTRB mixture. A possible explanation for this distinct relationship is most likely due to the difference in RAP contents. For the 40% RAP CTRB, 60% aggregate base content in the sample mixtures contained more aggregate particles that were available to be "glued" by the hydrated cementitious materials. In addition, a higher proportion of aggregate content provided better aggregate interlock between aggregate particles in the samples. In the case of the 60% RAP CTRB mixture, the asphalt-coated RAP aggregate particles limited the affinity to hydrated cementitious materials and the aggregate interlock between RAP particles was reduced because of a lack of surface texture.

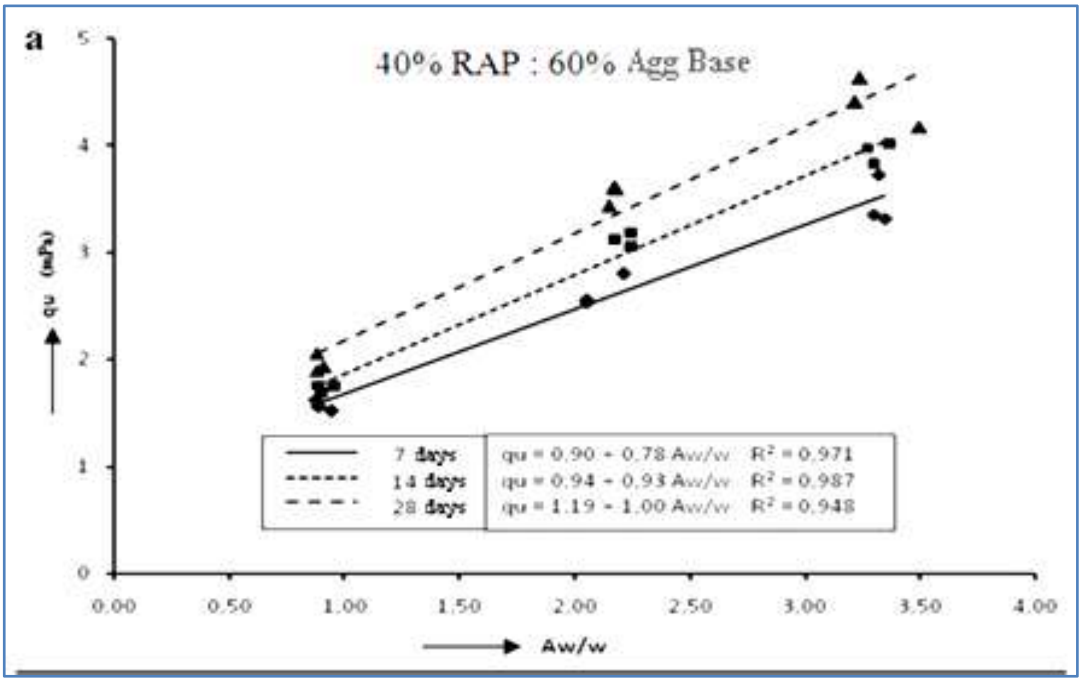

Figure 3. UCS (q_u) Vs Aw/w ratio at 7, 14, and 28 days of curing time.

Based on these observations, the efficiency factor of trass depends on the proportion of cement in the mixtures.For cement contents ≥ 4% in the two CTRB mixtures, the empirical equations to relate the efficiency factor **α** with cementitious materials and water content are proposed as Eq. 5 and Eq. 6 for 40% RAP CTRB, and Eq. (7) for 60% RAP CTRB:

α_1 = 4,033 + 14,577 **(W/C_{iv}+ Fw)** **R^2 = 0,9559** (for 15% trass) .... (5)
α_2 = 1,620 + 5,917 **(W/C_{iv}+ Fw)** **R^2 = 0,8977** (for 30% trass) .... (6)
α = 0,939 +2,266 **(C_{iv}/W + Fw)** **R^2 = 0,6159** .... (7)

Table 5. K and a Values

Curing Time	40% RAP : 60% RAM		60% RAP : 40% RAM	
	a	K (MPa)	a	K (MPa)
7 Days	1.149	0.7845	0.355	1.2534
14 Days	1.010	0.9257	0.019	1.2399
28 Days	1.191	0.9975	0.836	1.0484

3.3. Unconfined Compressive Strength (UCS)

The results show that the increase in cementitious material content (c_{iv}^*) slightly increased the q_u for both of the CTRB mixtures. An exponential function fits well with the assumed relationship of the q_u and the c_{iv}^*. The decrease in porosity value increased the q_u. Based on the unique specification for CTRB and CTRSB (Bina Marga, 2006), the UCS value for CTRB was 35 Kg/Cm^2 (3,5 MPa) at 7 days of curing with 100% CBR.

An exponential model fits well with the relationship between q_u and porosity for all cementitious material contents in the tested samples. This beneficial effect of a decrease in porosity in cement-stabilized materials has been reported by several researchers (e.g.,Consoli et el., 2011). Figure 4 shows the relationship between UCS q_u and η/c_{iv}^*. The model shows q_u depends on the ratio of porosity to cementitious material content (η/c_{iv}^*) for both CTRB mixtures. An increase in cementitious material content increased the q_u, while an increase in porosity reduced the q_u. This research study proposes the existence of a close relationship between q_u and η/c_{iv}^*, where the c_{iv}^* is the volumetric cementitious materials content expressed as a volumetric percentage of cementitious material of the total sample volume. The relationship between q_u and η/c_{iv}^* implied that η/c_{iv}^* has a distinct effect on both variables (i.e., η and c_{iv}^*) as a unique factor in controlling the q_u.

3.4. Strength Evaluation Analysis

This research project used a mathematical model to predict the strength of the CTRB mixtures with partial replacement of cement with trass. This proposed model, using porosity and cementitious material content ratio in conjunction with the proposed efficiency factor of both CTRB mixtures, is based on Feret's equation as follows:

q_{ult}(MPa) = 0.077 $(\eta/c_{iv}*)^{-1.490}$ R^2 = 0.88 .... (8)
q_{ult}(MPA) = 0.473 $(\eta/c_{iv}*)^{-0.845}$ R^2 = 0.82 .... (9)

Eq. (8) and (9) can be used to predict strength in a job mix formula for the two CTRB mixtures and were reasonably accurate within the range of cementitious content, porosity, and curing time in this research project. Based on the results of the CTRB mixtures, there were several dependent parameters to predict the q_u target value for a given mix. They were: cementitious materials content variation, porosity, and/or curing time period.

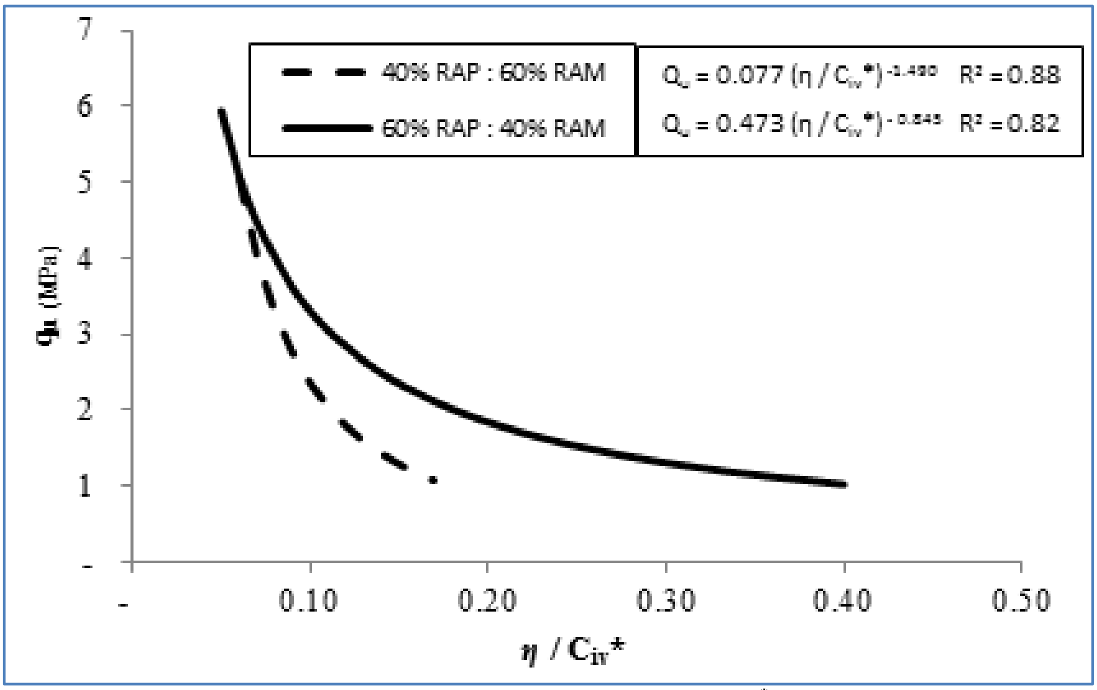

Figure 4. Relationship of UCS vs η/Civ*

IV. CONCLUSION

Based on the results, several significant conclusions can be drawn:

[1]. This research study was the first known effort to propose a proportional mixture method based on index porosity to cementitious materials content ratio and has a fundamental role in the assessment of the predicted Unconfined Compressive Strength of CTRB incorporating natural pozzolan (trass) by adding or partially replacing Portland cement. The dependent relationship among the parameters listed above was presented for each CTRB mixtures in relation to $\mathbf{q_u}$ with **η** and $\mathbf{c_{iv}}^*$.

[2]. Based on observations of the properties of CTRB mixtures with high RAP content and finer aggregate material, there were some parameters that influenced the UCS. Given porosity, **η**, cementitious material content, $\mathbf{c_{iv}}$*****, and curing time period for a given porosity to cementitious material ratio, **η/**$\mathbf{c_{iv}}$*****, the predicted UCS showed good correlations with those parameters. The UCS was substantially higher than that of the lower RAP content and coarse CTRB mixture as a consequence of the higher degree of aggregate interlock between particles. The most possible explanation is the presence of asphalt on the surface of the RAP and the particle shape of the trass that acted as a compaction aid during compaction of the samples. However, this phenomenon is only valid for samples with a cement content of >4%.

[3]. The potential and efficacy of including natural pozzolan (trass) from Manado, Sulawesi Utara, Indonesia, into CTRB mixtures as pavement bases could be successfully implemented in the field to improve the properties of the pavement base material. However,the efficiency factor of trass in this research study depended on the cement proportion and characteristics of trass used in the CTRB mixtures.

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