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PENETRATION DEPTH STUDY FROM PREVIOUS EMPIRICAL FORMULA OF MODIFIED FOAMED CONCRETE SLAB UNDER LOW IMPACT LOAD FROM A NON-DEFORMABLE IMPACTOR

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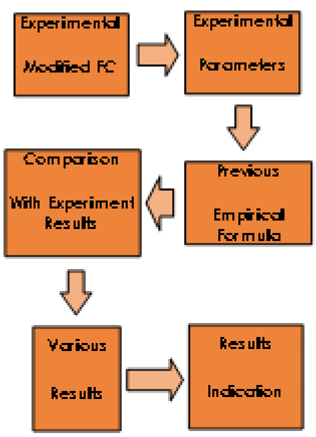
Graphical abstract



Abstract

The Modified Foamed Concrete (FC) was acheived by replacing sand with Rice Husk Ash (RHA) and experimental result has shown an increased in the compressive strength compared to conventional FC. This increase in compressive strength is required by FC to withstand impact loading. The experimental parameters from the modified FC subjected to impact loading were incorporated into previous empirical formula's, such as National Defense Research Committee (NDRC) [8], [18]), Ammann & Whitney [8], and Hughes [9] formulas. The calculation showed differences in results due to its variation and multiple approaches of the empirical formula. However, it is noted that the modified FC did not produce much differences with the conventional FC when it is subjected to impact loading. The calculation of previous formulas have indicated and highlighted these findings.

Keywords: Foamed concrete, impact, rice husk ash, modified foamed concrete

Abstrak

Modifikasi konkrit berbusa yang ditambahkan Abu Sekam Beras (ASB) telah meningkatkan kekuatan mampatan daripada konkrit berbusa. Yang mana kekuatan mampatan diperlukan konkrit berbusa untuk menahan beban hentaman. Parameter modifikasi konkrit berbusa yang dibebani hentaman pada kajian makmal digunakan untuk rumusan empiris kajian terdahulu, seperti National Defense Research Committee (NDRC) [8], [18], Ammann & Whitney [8], dan Hughes [9]. Hasil pengiraan menunjukkan pelbagai hasil disebabkan perbezaan keadaan pendekatan daripada rumusan empiris kajian terdahulu. Modifikasi konkrit berbusa tidak ada perbezaan kecenderungan dengan konkrit berbusa biasa ketika mereka dibebani oleh beban hentaman. Kajian rumusan terdahulu telah mengindikasikan hasil tersebut.

Kata kunci: Konkrit berbusa, impak, abu sekam beras, modifikasi konkrit berbusa

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1.0 INTRODUCTION

Foamed Concrete (FC) is categorised as lightweight concrete and nowadays it has been widely used as a normal concrete material or another lightweight concrete due to its numerous advantages. Factually, FC has the potential to be a protective structure, since it has been recorded elsewhere that the material has good characteristics to absorb energy impact [1][2]. However, as a protective structure, FC needs more strength than usual. Therefore, a modification to FC's composition improving its strength without losing its characteristic to absorb energy impact is required [3]. Previous research have shown that adding FC with polypropylene [4] and FC with Rice Husk Ash (RHA) [5] increases its strength and have good impact resistance. Interestingly, the research also observed that the behaviour under impact of modified FC by RHA or Polypropylene did not differ greatly from the conventional FC. This is an indication that modified FC has good energy absorption characteristic similar to conventional FC [4-7].

Corresponding to the penetration depth, and by using previous formulas from other researchers to the modified FC should be conducted and studied for comparison and clarity. The comparison is required as a case study to find out the reliability and accuracy of existing model formulas to modified FC. In this investigation, the existing model formula from Ammann & Whitney [8] and Hughes [9] were selected and will be incorporated with parameters from the experimental work of modified FC. In this case, the parameters available from the modified FC chosen are the FC added by RHA as a part replacement for sand [5].

Researchers [9-12] have classify the impact effect as dependent on its hardness and density of both impactor and concrete target. On the other hand, other researchers from [8][13-15] have also observed that the impact effect could also be classified by its velocity range. Even then, it has also been stated by [16], [17] that local impact effect by small fragments were generated by different types of explosions. This small fragments impactor was confusing, especially in terms of its hard impactor classification. With different research background and numerous findings, most investigators will eventually produce diverse empirical formulas. These formulas will have taken into consideration several classification of parameters such as its concrete target; target shape, target size, aggregate; aggregate texture, aggregate types, reinforcements; including its amount and arrangements and concrete strength and properties. Therefore, a need to compare these previous formulas using available parameters of impact from the modified FC [5] is deem necessary for further clarification.

Since 1940's the National Defence Research Committee (NDRC) [15] have conducted research and contributed towards predicting the penetration depth of conventional concrete. Hence, NDRC formula is essentially the basis and a reference to most researchers. Since then numerous formula to predict penetration depth have been established however, two contemporary formulas by Ammann & Whitney [8] and Hughes [9] have been selected. All three formulas will be employed to predict the penetration depth of slab targets from a current experimental research work from [5]. The parameters from the experimental work include its strength, diameter of impactor, nose shape impactor, and low impact velocities (7.7, 8.9 and 9.9 m/s). The paper henceforth presents and discusses the various results obtained.

2.0 DIMENSIONLESS PENETRATION DEPTH PREVIOUS FORMULA

Most researchers produced empirical formula of penetration depth prediction from their investigation on conventional concrete target. In 1976, Kennedy [8] published a review paper studying various empirical formulas (including NDRC, Ammann & Whitney, Petry 1, Petry 2 and ACE formulas) on the analysis and design of concrete structures to resist missile impact. Kennedy [8] also acknowledged that NDRC formula has been widely used as a model by other researchers to predict its penetration depth of conventional concrete. From observation NDRC formula gave the closest results compared to other empirical formulas as presented in Figure 1. It should also be noted that the NDRC formula are for typical missile with high velocities of up to 300m/s [18]. However, some researchers have adopted or compared NDRC formula for low velocity in predicting penetration depth [12].

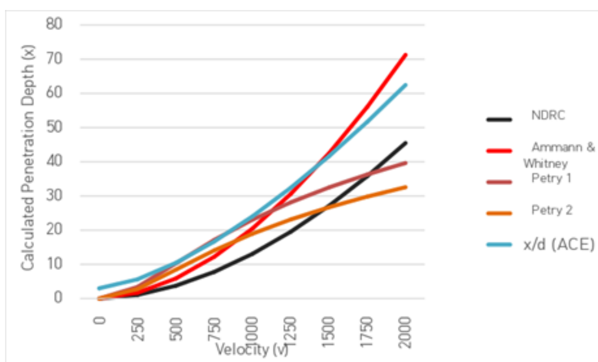

Figure 1 Calculated penetration depth of concrete: NDRC [8], [18], Ammann & Whitney [8], Petry 1&2 [8], Army Corp Engineers (ACE) [8]

2.1 NDRC Formula [8], [18]

NDRC is a theory of penetration for non-deformable projectile to penetrate the massive concrete, with good approximation of the experimental result. However, NDRC is the refinement and development of earlier formulas such as Petry formula, Army Corps Engineers (ACE) [8]. Furthermore, Li, *et al*. [18], presented the original expression of NDRC to SI unit as follow:

$$G = 380 \times 10^{-5} \frac{N^* M}{d\sqrt{f_c}} \left(\frac{V_o}{d}\right)^{1.8} \quad (1)$$

Where, x is penetration depth, d is diameter impactor, M is mass of impactor, f_c is compressive strength of concrete, V_o is impact velocity of projectile, and N^* is the nose shape factor equal to 0.72, 0.84, 1.0 and 1.14 for flat. Hemispherical, blunt and very sharp noses respectively. Upon the determination of the G function, the penetration depth x can be calculated in function of x/d as follows:

$$G = \left(\frac{x}{2d}\right)^2 \quad \text{for} \quad \frac{x}{d} \le 2 \quad (2)$$

$$G = \frac{x}{d} - 1 \quad \text{for} \quad \frac{x}{d} > 2 \quad (3)$$

2.2 Ammann & Whitney Formula [8]

This formula predicts the penetration of missile on concrete target resulting in relatively high velocity of small fragments. Factually this formula is similar to the NDRC formula. The formula provided in S.I. unit:

$$\frac{x}{d} = \frac{6 \times 10^{-4}}{\sqrt{f_c}} N^* \left(\frac{M}{d^3}\right) d^{0.2} V_o^{1.8} \quad (4)$$

2.3 Hughes Formula [9]

Hughes [9] has assumed that the penetration resistance offered by the target material subjected to missile impact increases linearly. This assumption is similar to the NDRC formula:

$$\frac{x}{d} = 0.19 \frac{N_h I_h}{S} \quad (5)$$

Where, N_h is nose shape factor which is equal to 1.0 for flat nose, 1.12 for blunt nose, 1.26 for spherical nose, and 1.39 for very sharp nose shapes, and I_h is a non-dimensional impact factor which can be obtained by calculating:

$$I_h = \frac{M V_o^2}{f_t d^3} \quad (6)$$

Hughes [9] uses the tensile strength $\boldsymbol{f_t}$ rather than the compressive strength in his formula. However, the ratio of tensile strength of concrete to the compressive strength of concrete is normally constant. It should also be noted that the dynamic strain rate effect on tensile strength concrete is different from the dynamic strain rate effect on compressive strength of concrete. This problem was eventually avoided when Hughes [9] obtained the $\boldsymbol{S}$ value through an empirical formula as shown below:

$$S = 1.0 + 12.3 \ln(1.0 + 0.03 I_h) \quad (7)$$

3.0 EXPERIMENTAL

3.1 Materials and Slab Production

Mix proportion and slab production of FC added by RHA was based on previous research [5][6], which the pre-foaming method were conducted to produce the FC with RHA and to pursue the target density of 1800 Kg/m3. Base on concrete mix containing cement, sand, and water were blended with a cement-water ratio of 0.60 and cement-sand ratio of 0.25 [19]. Furthermore, the stable preformed aqueous foam were made separately. The density of foam at 50 Kg/m^3 for preparation of aqueous surfactant solution was diluted by water at ratio of 1:5 [20][21]. Afterwards, the stable foam were blended gently into the base mix until reaching its target density.

RHA was obtained from various rice manufacturer and subjected to uncontrolled burning under 700°C for up to ± 6 hours. The composition of cement-sand-RHA was 1:3:1 with 1.25 ratio of RHA-water. The RHA was mixed into concrete admixture before foam was blended into the admixture. FC added by RHA admixture were molded to produce 600 mm x 600 mm x 160 slab target and maintained at temperature of 23 ± 2°C for 28 curing days [9][18][22][23]. This study also produces a conventional FC slab target with density of 1800 Kg/m^3 as control.

3.2 Impact Test

An instrumentation falling-weight impact tower was constructed to conduct the impact load test. The impactor was released from various elevations at 5m, 4m and 3m generating velocities of 10 m/s, 8.9 m/s and 7.7m/s respectively. The impactor is a non-deformable ball shape is made from urethane and polymer composite with 6 kg by weight, 218mm diameter and 1094 kg/m^3 of density. The ball shape impactor represents the model of a non-deformable projectile with a blunt nose. The standard compressive stress test and splitting tensile stress test was conducted to obtain the strength properties of FC with RHA [5][6].

4.0 DISCUSSION AND ANALYSIS

Table 1 presents the calculated penetration depth, *X* (mm) from Ammann & Whitney [8], Hughes [9], and NDRC [8][18] formula. The calculations applied all parameters of the current experimental such as, velocities, mass, and diameter of impactor. This includes the strength characteristic of target slabs. A blunt nose impactor in current experimental work was represented by a nose shape factor of 0.84, 1.26, and 0.84 from Ammann &Whitney [8], Hughes [9], and NDRC [8], [18] respectively. Table 1 also includes the experimental penetration depth values and comparison was made (in percentage differences) to the calculated penetration depth.

Table 1 Comparison between calculated penetration depth to experimental penetration depth

Materials	Velocities (m/s)	Penetration depth , X (mm)			
		Current Experiment	Ammann & Whitney Formula	Hughes Formula	NDRC Formula
FC + RHA (%Diff)	7.7	2.2	4.5 (+105%)	2.19 (-0.5%)	0.29 (-87%)
FC + RHA (%Diff)	8.9	2.9	5.8 (+100%)	2.63 (-9%)	0.37 (-87%)
FC + RHA (%Diff)	9.9	3.7	7.1 (+92%)	3.02 (-18%)	0.45 (-87%)
FC (%Diff)	7.7	2.4	3.9 (63%)	1.52 (-37%)	0.25 (-90%)
FC (%Diff)	8.9	3.1	5.1 (+65%)	1.78 (-43%)	0.32 (-90%)
FC (%Diff)	9.9	3.9	6.2 (+59%)	2.01 (-48%)	0.39 (-90%)

The results indicate that Ammann & Whitney's [8] formula overestimated the values with substantial differences from the experimental results. For FC, differences ranging from +59% up to +63% was observed, unlike for modified FC+RHA where higher differences from +92% up to +105% was recorded. It was known from Kennedy [8] that Ammann & Whitney's [8] formula was designed for high velocity and was not intended for velocity below 150 m/s. Hence, the large differences in Table 1 was observed. Kennedy [8] also observed that Ammann & Whitney's formula depended on values of penetration coefficient for a specially designed reinforced concrete target. Simultaneously, Ammann & Whitney's [8] formula have a nose factor value similarly defined by NDRC [8], [18] indicating that the impactor in Ammann & Whitney's [8] formula was not a rigid impactor.

Hughes [9] formula achieved the closest value with the experimental results but the formula gave an underestimated values for both modified FC+RHA and conventional FC. However, moderate differences for modified FC+RHA was observed from -18% to -0.5% only, compared to conventional FC where a much higher differences from -48% to -37% occurred. From literature, it was known that Hughes formula uses the tensile strength of concrete (**f_c**) instead of the compressive strength (**f_t**) [24]. Although, the penetration resistance is dominated by **f_c**, however, Hughes [9] defined that the ratio between tensile and compression strength of concrete is constant. Therefore, using **f_t** or **f_c** causes only a difference of the constant. This influences the strain-rate effect, **S** of Equation 7. The strain rate effect on the tensile strength of concrete (**Sf_t**) is different from the strain rate effect on the compressive strength of concrete (**Sf_c**) [9], [18]. Based on Equation 2, Hughes [9] formula will predict value of **Sf_t** of FC with RHA. Since **f_t** is lower than **f_c** (see Table 2). Hence, Hughes [9] formula resulted in values which is lower than the experimental results (see Figure 2).

NDRC [8], [18] formula produces a much lower penetration depth values showing large differences for both modified FC+RHA and conventional FC. The formula underestimated the experimental values from -90% to -87% difference. However, in the present study, the target slab is an FC with RHA, where the behaviour of both tensile and compressive strain rate differs with rigid concrete. The FC with RHA is low in strength and in the elastic range, the strain is fickle. This condition causes the NDRC [8], [18] formula as expressed by Equation 1 to obtain shallower penetration depth than the experimental results.

Comparing the current experimental work between modified FC+RHA and conventional FC, Table 1 shows that the penetration depth result did not show substantial improvement. This is indicated by the penetration depth values measured at 2.4mm to 2.2 mm for FC to FC+RHA at velocity of 7.7 m/s, followed by 3.1mm to 2.9mm for FC to FC+RHA at velocity of 8.9m/s and 3.mm to 3.9mm for FC and FC+RHA.

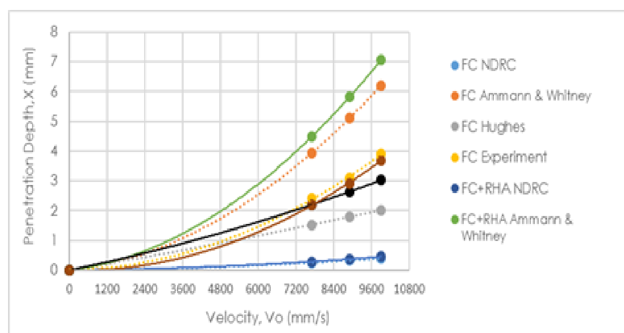

Figure 2 Comparison of Penetration depth from Ammann & Whitney [8], Hughes [9], NDRC [8][18], and Current Experimental for FC and FC +RHA

Figure 2 shows graphically the comparison of penetration depth result from NDRC [8], [18], Ammann & Whitney [8], Hughes [9] and current experimental values.

Table 2 Strength properties of slab target

Strength	FC	FC +RHA
Compressive Strength (N/mm^2)	6.19	10.49
Tensile Strength (N/mm^2)	4.27	4.29

5.0 CONCLUSION

As a conclusion to the above discussion, it can be observe that Ammann and Whitney's formula overestimated the penetration depth values for both modified FC+RHA and conventional FC. Hughes and NDRC formula gave lower values, underestimating the penetration values as shown in Table 1. Overall, it can be seen that the modified FC+RHA (as replacement of fine aggregate) when compared to FC does not have much effect when subjected to low impact load where penetration depth shows slight improvements. However, these differences are within acceptable range.

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