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INTRINSIC PROPERTIES OF BRICK AGGREGATE CONCRETE: A REVIEW

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Abstract. *Higher porosity in brick aggregates originating from the brick burning process induces increased permeability and reduced durability properties in brick aggregate concrete compared to those in conventional stone aggregate concretes. The modulus of elasticity of brick aggregate concrete is relatively low, giving rise to larger deformations and dilation property under axial stress. In light of recent building collapses and factory fires in Bangladesh, it has become essential to critically characterize brick aggregate concrete in terms of its fundamental properties not only to forecast the future of existing structures but also to formulate an effective strengthening procedure. This paper reviews recent research findings on mix design, effect of discontinuous curing, shear strength, tensile strength, fracture behavior, post-peak fracture process, creep and shrinkage behavior, non-destructive test correlations and fire endurance properties. Recycling of brick aggregate concrete is briefly discussed in terms of its promises and challenges for making future construction processes greener and friendlier to the environment. The necessity for updating future codes and standards for brick aggregate concrete structures with lower life cycle cost is emphasized.*

Keywords: *Brick Aggregate Concrete, Mix Design, Curing, Modulus of Elasticity, Dilation, Confinement, Fracture Behavior, Creep and Shrinkage, NDT Correlations, Fire Endurance, Structural Strengthening, Recycling.*

1 INTRODUCTION

The geographical location of present Bangladesh has observed multiple transformations in its political boundaries in the last century. The land once formed the eastern part of Pakistan, which was created from British India in 1947, and emerged later as an independent country after the War of Liberation in 1971. In the definition of the new political boundaries of 1947, the Rajmahal Hills and the Shillong Massif, i.e., the nearest sources of rocks suitable for concreting, went to India, leaving the land only with recent soft sedimentary deposits [1-3]. Such deposits do not readily qualify for use in concrete as coarse aggregates. In this scenario, the use of crushed bricks (Figure 1), first explored in Germany in 1860, became a widely practiced option in the construction industry of this land. The German construction industry adopted this approach widely after the Second World War through the utilization of masonry rubbles [4]. Recent studies on the use of crushed bricks as aggregates in concrete have also been reported in some European and American countries [5].

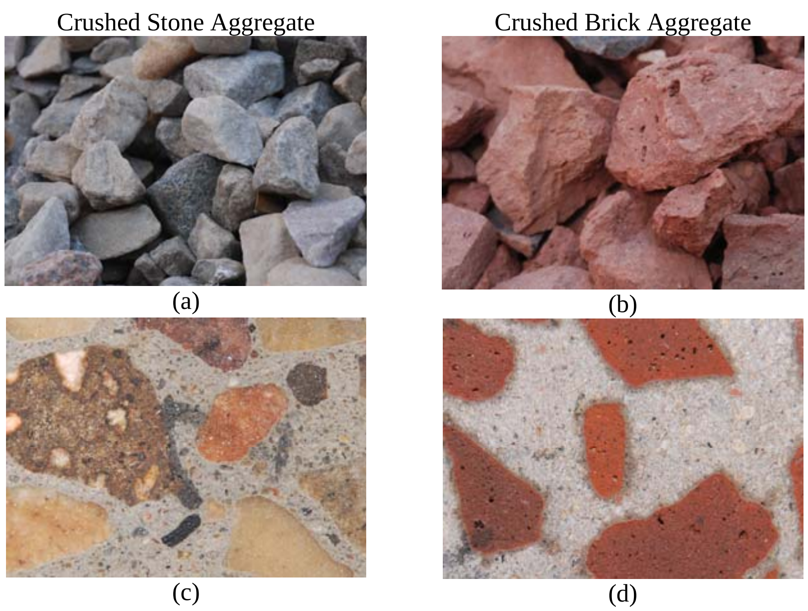


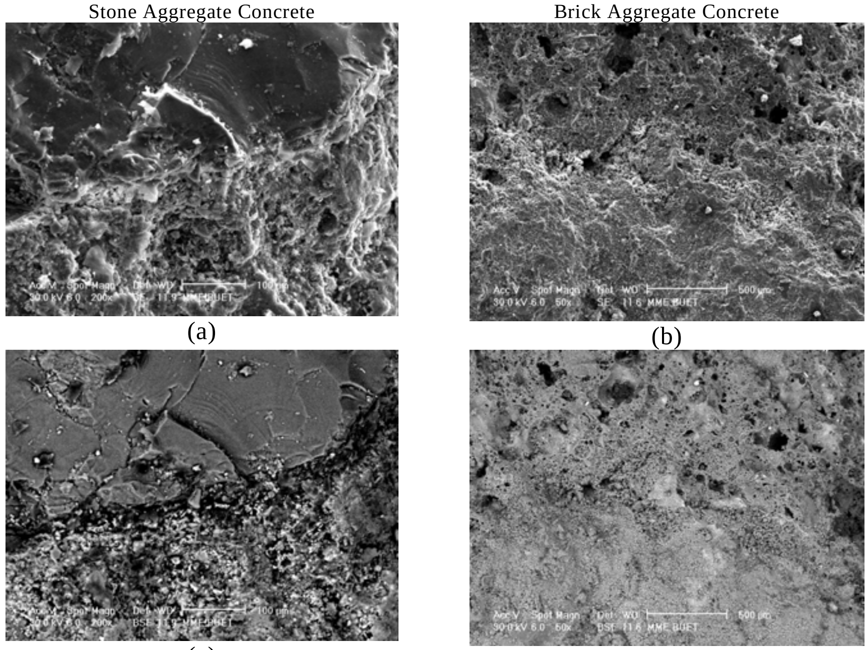
Figure 1: Stone and brick aggregates in concrete making. (a) Stone aggregate, (b) Brick aggregate, (c) Saw cut surface of stone aggregate concrete, (d) Brick aggregate concrete. Images by: A.F.M.S. Amin

However, a few catastrophic building collapses [6-7] that occurred in Bangladesh in the recent past have been linked with the use of brick aggregate concrete. Furthermore, the use of burnt clay bricks is not very friendly to the environment as it uses top soil from agricultural land, thus reducing its fertility, and also uses natural gas/ coal / fire wood in brick kilns, producing large amounts of greenhouse gases. This has motivated researchers to explore its fundamental engineering properties, which differ significantly from those of conventional stone aggregate concrete. This paper attempts to comprehensively review these developments to provide directions for the future use of brick aggregate concrete, evaluate existing structures, and strengthen and recycle demolished/unusable brick aggregate concrete structures into next generation concrete products.

2 BASIC PROPERTIES AND MICROSTRUCTURE

Figure 2 presents the scanning electron microscope (SEM) images of brick aggregate concrete and stone aggregate concrete. Back scattered images are also presented for comparing the mortar aggregate interface. The comparison shows the existence of porosity in the brick aggregate (Figures 2b and 2d). The interface between the coarse aggregate and mortar is observed to be denser in the brick aggregate concrete than in the stone aggregate concrete.

Stone Aggregate Concrete | Brick Aggregate Concrete



(a) (b) (c) (d)

Figure 2: Micrographs of concrete. (a) Stone aggregate concrete; (b) Brick aggregate concrete (RB); Back scattered images of (c) stone aggregate concrete and (d) brick aggregate concrete to illustrate the interface and porosity within the coarse aggregate. The coarse aggregate is in the upper part of each image. Images by: A.F.M.S. Amin.

Burnt clay bricks are crushed and sieved to make aggregates of required gradation. Table 1 presents the typical material properties of brick aggregate in comparison to conventional stone aggregate. Brick aggregates have lower unit weight, higher absorption capacity and a higher Los Angeles Abrasion value than stone aggregates [8]. The porosity in the microstructure (Figure 2) can be attributed to the first two properties, while the last property is related to the brick burning process and mineralogical components of the clay itself. Some well-known mix design methods, such as ACI Methods of Mix Design, cannot be applied directly to designing mixes for brick aggregate concrete [9-12] as these methods unrealistically suggest the use of a large volume of fine aggregates for a given volume of cement. In addition, brick aggregates cast in the saturated state for making concrete act as an internal curing agent due to the presence of pores in the microstructure (Figures 1b, 2b, 2d). This makes brick aggregate concrete less susceptible to discontinuous curing [13] than stone aggregate concrete.

3 RECENT PROBLEMS

3.1 Durability

The poor performance of brick aggregate concrete in a saline environment provided the engineers of Bangladesh very early hints on the durability problems of such concrete back in the 1990s when cyclone shelters [14-15] constructed in the coastal areas of Bangladesh were becoming aged (Figure 3) very rapidly within 15 years of construction. Later, although at a slower pace, durability problems resulting in spalling of cover concrete due to corrosion in reinforcements became visible in many buildings and bridges across the country in the last three decades. The high permeability of the concrete can be linked to this phenomenon that is observed in the field.

3.2 Building Collapses and Factory Fires

The two recent major building collapses in the country, i.e., Spectrum Sweaters in 2005 and Rana Plaza in 2013 [6-7], used brick aggregate concrete; however, the properties of brick aggregate *per se* were not directly linked to these collapses. Furthermore, in the recent past, a few post fire incidences also indicated the necessity of knowing the behaviors of brick aggregate concrete under fire so that residual compressive strengths can be evaluated after a fire incident.

3.3 Emerging Key Issues

The use of brick aggregate in concrete making has been practiced for many years. With time, on the one hand, old buildings are starting to show signs of aging; on the other hand, to keep pace with the economic development, many medium to moderately high-rise buildings are also getting constructed with brick aggregate concrete. In this scenario, it is becoming very important to critically assess the fundamental strength and durability characteristics of brick aggregate concrete not only for having a rational design but also to forecast the future of existing structures. A building that is currently in use but becoming quite poor in its condition cannot always be replaced immediately with a new one. Therefore, a strengthening methodology is often required for such marginally unsafe structures to extend their life spans. In addition, premises on the recycling of demolished products from such concretes into new constructions also need to be investigated. Such ideas do have the potential to redefine the fabric of civil engineering through updating the codes and standards of the country in a more rational way. The availability of a trusted research base, however, is required to ultimately achieve this goal. A summary of the present knowledge base is presented in the next few sections.

Table 1.
Typical material properties of coarse aggregates from crushed stone and brick

Material properties	Coarse aggregates from	
	Brick	Stone
Bulk specific gravity (OD)	1.83	2.64
Bulk specific gravity (SSD)	2.12	2.66
Absorption capacity (%)	16.0	0.51
Unit weight (SSD) kg/m^3	1094	1493
Unit weight (OD) kg/m^3	953	1476
Los Angeles Abrasion Value (%)	41	30

OD: Oven dry, SSD: Saturated Surface Dry

(a) (b)

Figure 3: Typical deterioration of reinforced concrete in coastal areas.
(a) Beam, (b) Slab [14].

4 ENGINEERING PROPERTIES

4.1 Modulus of Elasticity and Dilation

The modulus of elasticity of concretes made with brick aggregate is much lower than that of stone aggregate concrete of similar strength [8, 16]. The larger deformability offered by the former due to the existence of void filled soft microstructure must be one of the reasons leading to this property. Nevertheless, a reduction in the modulus of elasticity generates a larger dilation [17]. Concrete is the material that is most widely used to carry compression. An increase in the dilation property demands attention in the design to not only ensure confinement in the axial members [18] but also in the members where structural behavior is predominantly governed by principal compression, e.g., a beam [19] and its flexural strengthening.

4.2 Strength Properties

The flexural shear and the split tension strength of brick aggregate concrete is reportedly higher than those of stone aggregate concrete of comparable compressive strength [8, 20]. However, no justification from the microstructure is yet recorded in the current literature.

4.3 Fracture Behavior and Post-peak Fracture Process

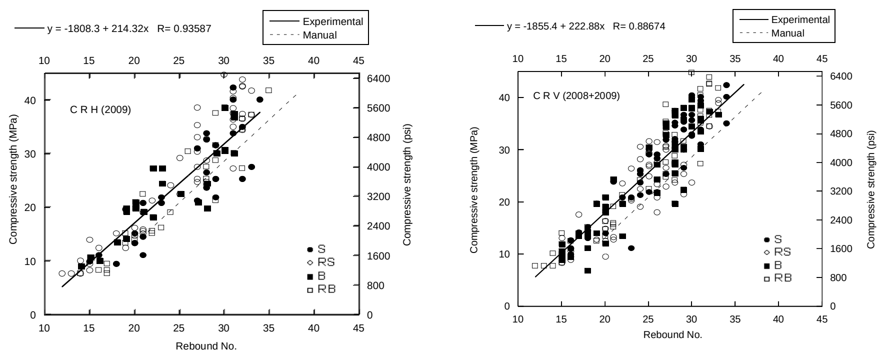
The presence of initial micro-defects in coarse aggregates results in crack formations at a stress lower than that in stone aggregate concrete [18]. Thus, passively confined brick aggregate concrete under axial load internally cracks at a comparatively lower axial strain. This phenomenon induces larger axial strain on the confinement. A very rapid collapse of the member under compression due to a complete disintegration of the core concrete can occur. In the case of stone aggregate concrete columns, the intensity of crack development is much lower. This characteristic difference in the property indicates the extremely brittle behavior of brick aggregate concrete.

4.4 Creep and Shrinkage

Creep strains in brick aggregate concrete are distinctly higher than those in stone aggregate concrete [21]. This indicates the necessity of revisiting the code provisions stipulating the deflection criteria in designs using such concretes. Although the feasibility of using high strength concrete made with brick aggregates was investigated in the early 1960s [22], the observation of a large creep strain needs to be specially considered in the design of such structures and for predicting their long-term behaviors. Currently, some works are ongoing at the Bangladesh University of Engineering and Technology studying the shrinkage properties. No results are yet available to the public domain.

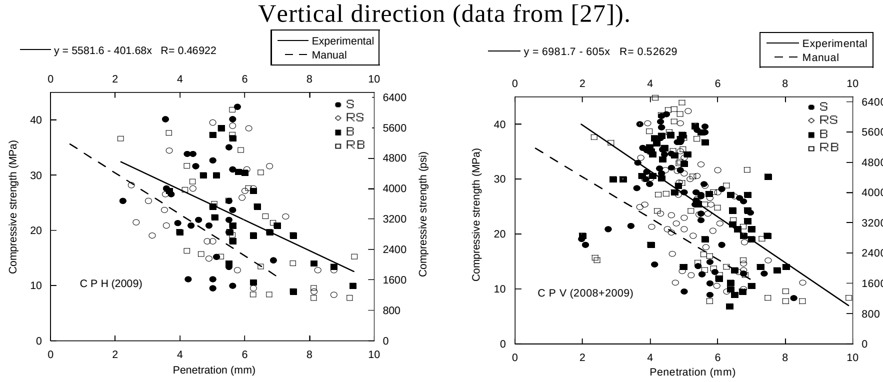
5 NDT CORRELATIONS

Rebound number, penetration resistance values, ultra-sound pulse velocities and core strengths are widely used as non-destructive and semi-destructive test methods to evaluate the in situ strength of existing structures. In all these measurements, the rebound number, penetration, velocity or core strength results determined using a standard method, e.g., American Society for Testing and Materials (ASTM) method [23-26], is correlated with standard concrete specimen strengths for evaluation purposes.



(a) (b)

Figure 4: General regression graphs for penetration resistance value vs. compressive strength for different aggregate types. (a) Horizontal direction; (b) Vertical direction (data from [27]).



(a) (b)

Figure 5: General regression graphs for penetration resistance value vs. compressive strength for different aggregate types. (a) Horizontal direction; (b) Vertical direction (data from [27]).

However, as per ASTM, the engineer needs to have a dependable correlation for the concretes under test. Therefore, a validation of standard and known correlations for strength assessment is required. To this end, some recent efforts conducted at the Bangladesh University of Engineering and Technology can be noted [27] where many concrete specimens were subjected to such tests before crushing directly under compression. Figures 4-5 present the correlations obtained for different aggregates. Interestingly, no significant difference in the rebound hammer response is found for the variation in aggregate properties. The pin used in the penetration resistance test has a smaller response area than the rebound hammers. This yields poor correlation values in a comparison of Figures 4 and 5.

Currently, a detailed evaluation of core strength is being conducted. The correlation for ultrasound velocity and compressive strength is found to be significantly dependent on the specimen's degree of saturation.

6 FIRE ENDURANCE

Brick is produced by burning clay in a fire at a high temperature. Thus, the effect of high temperatures on brick aggregate concrete was found to be less detrimental than that on stone aggregate concrete [28]. In testing concretes with a varied range of porosities, it was found that the strength loss is inversely proportional to the aggregate or concrete porosity as steams or fumes produced at a high temperature find vent paths for the release of internal pressure. However, the experiments suggested the existence of a local maximum in porosity where strength loss is the highest (Figure 6) since more internal pressure from vapor, steam and fume is generated with lesser vents for pressure release.

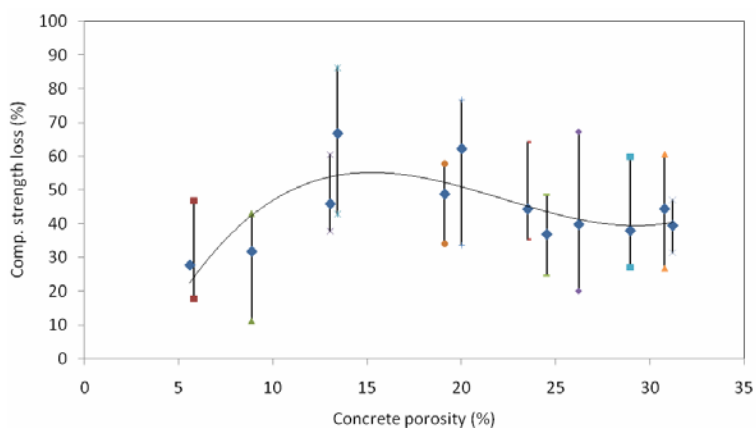


Figure 6: Effect of concrete porosity on compressive strength loss. (data from [28])

7 RECYCLING OF OLD CONCRETE

In light of globalization and increased connectivity with neighboring countries, the import of stones for concrete making is becoming more common. In addition, rocks are also collected from hard rock mines. With the current pace of development, however, a major stock of structures made from brick aggregates will be demolished for new construction, particularly in Bangladesh. In this context, efficient recycling of old brick aggregate concrete buildings needs to be emphasized. Recent works in this aspect have justified its feasibility [29]. This possesses an added benefit due to the existence of a residual cementing property [30]. To harness this beneficial property, old concretes need to be crushed mechanically. The obtained aggregates and fines should also be used before aging occurs due to ambient humidity. To this end, the use of recycled products obtained after crushing old brick aggregate concrete into aggregates and fines in non-structural and structural applications with low strength/durability requirements needs to be investigated. The use in road sub-base and for low grade concretes can be observed as prospective areas. Combining efficient collection, demolition, recycling and reuse policy together with demolition plants can help a nation in the long run.

8 CONCLUSIONS

Currently, no code provisions account for the intrinsic properties of brick aggregate concrete. Rather, the codes applicable to stone aggregate concrete are readily adopted. Furthermore, the correlations for evaluating existing brick aggregate concrete structures also depend heavily on those known for stone aggregate concrete. In this review, we provided ample peer-reviewed references that show characteristic differences in the properties of brick aggregate concrete from stone aggregate concrete. This clearly indicates the necessity of enacting new sets of code provisions to consider these fundamental properties. Furthermore, to conserve energy and protect the environment, efficient reuse of concretes from existing brick aggregate concrete structures is very much warranted. The development of an efficient demolition and recycling methodology will help engineers protect and conserve nature in moving with their creative works.

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