Performance of concrete produced with crushed bricks as the coarse and fine aggregate

JAFAR BOLOURI BAZAZ[1], MAHMOOD KHAYATI[2] & NAVID AKRAMI[3]

[1] *Assistant Professor, Civil Engineering Department, Ferdowsi University, P O Box 91775-1111, Mashhad, Iran.(e-mail: bolouri@ferdowsi.um.ac.ir)*
[2] *Graduate Student, Geotechnics Section, Civil Engineering Department, Ferdowsi University, P O Box 91775-1111, Mashhad, Iran. (e-mail: mahmood_khayati@yahoo.com)*
[3] *Undergraduate Student, Civil Engineering Department, Ferdowsi University, P O Box 91775-1111, Mashhad, Iran.*

Abstract: During the last decades, in most industry countries, a large number of old buildings has been demolished and million tons of construction demolition waste have been produced. Demolition waste around the cities not only is a serious threat to the environment and underground water sanitation, but results in unpleasant landscapes.

At present approximately 5% of bricks taken from demolition sites are being separated and recycled, while the proportion of concrete being recycled is up around 90%. This low rate of brick recycling is due to a lack of research into the performance of crushed brick material in applications such as concrete aggregate and road base. On the other hand, the low quality of crushed brick such as high water absorption and low strength in comparison with rock makes it difficult to meet concrete specifications.

The importance of recycling brick cannot be overemphasized, since clinker bricks make up a large portion of construction and demolition waste. Considering the environmental impacts, construction and demolition waste threatens the health and safety of large and developed cities. The investigations showed that, when properly organized, masonry clay bricks could be crushed, sieved and used as economically as aggregate to produce concrete products.

This research aims to examine a procedure to utilize clinker bricks in concrete and reproduce concrete bricks. The clinker bricks as a large portion of construction and demolition waste and are crushed and used as crushed coarse aggregate in concrete. Through an experimental program, physical characteristics of crushed clinker bricks, compressive and tensile strength of bricks concrete are investigated. Since the main objective of the research is to recycle clinker bricks, it is intended to produce concrete bricks so that comply with the standard requirements of clinker bricks. It is, therefore, desirable to produce concrete bricks to meet the strength of original clinker bricks. Also further researches were conducted to increase the quality of concrete produced with crushed bricks.

Résumé: Dans les décades passées en plusieurs pays industriels, un grand nombre des bâtiments sont détruits et leur restant est évalue à environ un million dé tonne. Ce genre des déchets est une menace sérieuse pour l'environnement et hygiène des eaux souterraines de surcroît il a un aspect qui frappe désagréablement à l'œil.

A présent, environ 5% des briques dans les déchets des bâtiments sont recyclées tandis que 90% ou presque du béton détruit est recyclé. Le niveau bas de recyclement des briques peut être a cause de manque des recherches dans leur application et utilisation en construction des routes. Il faut ajouter que la brique à cause de son mauvais comportement en compression et avoir un haut dégré d'absorption d'eau ne peut pas être utilisée facilement dans le béton.

La brique clinker comme brique écrasée s'occupe une grande partie des restants des bâtiments, les investigations ont montrées qu' àvec une méthode organisée on peut mouliner des briques écrasées après avoir tamisé, ainsi on peut l'utiliser dans les produits en béton.

Cette recherche est un essai d'utiliser des briques clinker dans béton par une procédure afin d'obtenir des produits en béton. Des briques clinker est une grande partie de déchets des constructions qui peut être écrasée et puis on peut l'utiliser dans béton comme gros agrégats.

Fondée sur une programme expérimentale, les caractéristiques physiques de brique clinker écrasée et la résistance en compression et en tension du béton produit par brique sont déterminés. Le but principal de cette recherche ayant de recycler des briques clinker ; il est favorable d'obtenir des briques en béton d'une façon qu' elles puissent avoir les exigences de norme, autrement dit d'avoir la résistance originale de brique clinker. Plusieurs recherches sont aussi faites pour améliorer les qualités du béton en brique écrasée.

Keywords: environmental protection, concrete, aggregate, laboratory tests, compressive strength, cement.

INTRODUCTION

In most developing countries, including Iran, the process of old urban fabric replacement with a new urban fabric is the most sophisticated characteristic of urbanization and modernizations, This pattern of urbanization in Iran is more evident in the central parts of large and developing cities. Iran during last decades is facing rapid growth population, resulting in more housing demands and new industrialization.

In the last decades, the rapid growth of urban population in most countries including Iran makes environmental degradation and pollution and these in turn constraint growth and development of large cities (Hadizadeh 2005).

Mashhad, as the second largest city in Iran and with an old urban fabric, enjoys tourism attractions with more than 20 million tourists annually. The potential of attractiveness for tourists in Mashhad is mainly due to the holly shrine of Imam Reza (the tomb of one of the Islamic leader, 720-780 AD), which is located in this city. Additionally, the historical and cultural potentials such as Ferdowsi (940-1020 AD) tomb, the greatest Iranian poet and also natural wonderful places around the city make this city the centre of attention in the country, attracting millions tourists and eager pilgrims from all other cities and peripheral countries. This demands the renovation of the fabric old, resulting in a huge amount of construction and demolition debris annually, which is a serious threatening to the environmental issues. Just last year 0.5 million tons of demolition wastes were produced in Mashhad (Report of Municipality of Mashhad, RTMO 2005), of which about 25 percent is recyclable brick or mortar cement/concrete. The disposal of this huge quantity of construction and demolition waste has become a severe social and environmental problem in the territory. The possibility of recycling of waste from the construction industry is thus of increasing importance. According to current practice, most of the construction waste is uncontrolled land filled, especially around the rivers and roads. This not only creates ugly landscapes around the city but also causes the underground water pollution and widespread destruction floods. A proper recycling of demolition wastes is therefore most important in order to have an acceptable material for utilization in concrete production (structural or non- structural concrete) and road constructions.

At present approximately 10% of bricks, which are unbroken and roughly in original form, taken from demolition sites are being reused for new masonry buildings. While the proportion of concrete is being recycled is up around 90% only a few percent of brick is being recycled. This low rate of brick recycling is due to a lack of research into the performance of crushed brick material in some applications such as road base material (Bolouri 2005). It is also worth mentioning that the masonry brick in Iran is produced in small, non-automated, and un-controlled factories. This results in these types of bricks suffer good quality and cause one to think that they are not appropriate as concrete aggregate or road layer construction. Considering the possibility of recycling this type of material the Municipality of Mashhad offered a research programme focusing on the following objectives:

- To identify the characteristics and components of Construction and Demolition Waste (CDW)
- To determine the mechanical properties of recyclable material including clay brick and concrete/mortar cement.
- To evaluate the strength of concrete using crushed clay bricks as aggregates
- To specify the bearing capacity of clay bricks as road construction layers materials, when stabilized with cement.

CHARACTERISTICS OF MASONRY CONSTRUCTION AND DEMOLITION WASTE

In Mashhad up to 0.5 millions tons of Construction and Demolition Waste are generated annually. Construction and Demolition Waste (CDW) is a mixture of different building materials. Its composition depends on the type of building, the age, the region, in which the building is located, the technique of demolition etc. The main components of CDW in Mashhad are soil, brick, concrete, wood and ceramic. Except soil, which is roughly 50% of CDW, the predominant materials, especially in buildings from the former century, are bricks and cement mortar/concrete. In younger buildings further materials like plaster boards, ceramics, wood and different types of materials for thermal insulation are used in an increasing extent.

In order to analyse the components of CDW, 50 samples from three different sites in which CDW are deposited were taken. The weight of each sample was around 25 kg. The samples were sieved over the sieve No. $1^{\#}$ (25.4 mm opening diameters) to separate soils and fine materials. The predominant composition of material <25.4 mm is soil which is not suitable for concrete. Different components of sieved samples were then separated and weighed. Table 1 shows the percentage of different materials in analyzed samples.

Table 1. Analysis of Construction and Demolition Waste (CDW)

Retained over sieve No $1^{\#}$ (%)	Brick (%)	Cement mortar (%)	Gypsum (%)	Asphalt (%)	Stone (%)	Ceramic (%)
24 - 80 %	10 - 42 %	6 - 28 %	0 - 7 %	0 - 5 %	2 - 23 %	0 - 9 %

It should be mentioned that the percentages of different materials vary from place-to-place and time-to-time. The amount of recyclable materials including brick and concrete, however, is noticeable.

MECHANICAL PROPRTIES OF CLAY BRICK

Strength and durability of concrete depend on various factors, among which the most important is the quality and properties of aggregate, such as porosity, water absorption, specific gravity, soundness, freezing and thawing resistance, and finally compressive strength. The following sections describe the necessary tests and the pertaining results for more identification the properties of clay bricks.

Compressive strength

The importance of using aggregates with good quality cannot be overemphasized since the fine and course aggregate generally occupy 60% to 75% of the concrete volume and strongly influence the physical and mechanical properties of concrete. Among these, the compressive strength of hardened concrete is relatively dependent on the strength of rocks, which are the main source of sand and gravel. The compressive strength of concrete made with crushed brick as aggregate is mainly due to the strength of brick in its original form. To examine this matter different bricks in their original form were randomly selected and loaded to failure at prescribed rate of 0.3 MPa/s, using loading machine (ISIRI, 2002). The results are summarized in Table 2. Although the compressive strength of various natural rocks varies greatly, however the compressive strength of most common rocks is relatively high in comparison with brick. The data gathered from different sources (Bowles, 1988) are shown in Table 2. The low compressive strength of brick in compared with different rock, will probably result in reduction in compressive strength of concrete when crushed brick is the main source of aggregate.

Table 2. Compressive strength of bricks in original form and rock (after Bolouri 2004)

Material	**Unconfined Compressive Strength (UCS), kg/cm^2**	**Specific gravity (gr/cm^3)**
Brick (in original form)	30 - 70	1.9-2.0
Basalt	1750-4200	2.8-2.9
Granite	700-2800	2.65-2.75
Limestone	350-1750	2.65-2.75
Sandstone	280-1400	2.3-2.4

The test results clearly indicate

- The UCS of natural rock is much higher than clay brick. This will defiantly reduce the compressive strength of concrete made with crushed brick in comparison of normal concrete.
- The water absorption of brick is about 12 times more than rock. This causes concrete made with crushed brick absorb more water in compare with concrete made with natural aggregates, although this ratio will not be the same for aggregate and concrete.

Shape and texture

The crushed clayey brick had well defined edge and was angular in shape, which resulted in a high surface-to-volume ratio. The surface of the crushed brick was rough and highly porous due to mineral structure of brick. No physical testing was performed to quantify the angularity of the material, however it was visually classified as having 100% crushed face. Chemical analysis of soil used to make bricks is given in Table 3.

Table 3. Chemical analysis of soil used to make bricks

SiO_2 (%)	Al_2O_3 (%)	Fe_2O_3 (%)	CaO (%)	MgO (%)	K_2O (%)	Na_2O (%)
50-55	13-18	4-6	8-12	2.5-4	0-1.5	0.2-0.5

Porosity and water absorption

The water absorption of brick (in original form) and crushed brick performed in accordance with ASTM 128 and ISIRI 2000, as shown in Table 4. The water absorption for crushed brick and natural aggregate was about 28 and 1.5 percent (in average) respectively. This significant difference is thought to be the main reason of reduction in strength and durability of concrete made with crushed brick. Low specific gravity of brick in comparison with natural aggregate resulted in the concrete made with crushed bricks to be lighter that normal concrete.

Table 4. Water absorption and specific gravity of materials

Aggregate type	**Water absorption** (%)	**Dry unit weight (g/cm^3)**
Brick (in original form)	25 – 28	-------
Crushed brick	26 - 30	950-1050
Natural rock	0.5 – 2.0	-------
Natural aggregate	1.0 – 3.0	1500-1700

Figure 1. The effect of 5 cycles of immersion of brick in sodium sulphate solution followed by drying in oven

Soundness of aggregate

In order to assess the soundness of aggregate when subjected to weathering action, a standard test method is recommended by ASTM C88 or AASHTO 104. The test is accomplished by repeated immersion in saturated solution of sodium or magnesium sulphate followed by oven drying to dehydrate the salt precipitated in permeable pore spaces. This test is designed for all materials used as road construction material, including recycled concrete and brick. However for many types of material for which chemical attack and abrasion are anticipated, the results may be misleading. The crushed brick was subjected to 5 cycles of immersion of samples in sodium sulphate solution followed by drying in oven. Figure 1 shows a piece of brick after 5 cycle immersion in sodium sulphate solution followed by drying. The cracks appeared in the sample indicate the low resistance of brick to weathering action.

Regarding the aggregates size, according to ASTM C33 they are divided as coarse (9.5 mm to 50 mm) and fine (0.3 mm to 9.5 mm) aggregates (Figure 2). After the completion of the final cycles and washing and drying, the samples were sieved over the same sieve on which they were retained. The loss in weight in proportion of the initial weight (as a percentage), which is known as aggregate soundness, is shown in Table 5.

The soundness test results for cement mortar/concrete indicate that the performance of concrete productions in this test is very weak which is mainly due to the destructive effect of sulphate on cement mortar/concrete. Perhaps for evaluation of cement mortar/concrete durability, is not suitable and the freezing and thawing test, described in the following section, could lead results that are more realistic.

Table 5. Soundness test results of crushed brick

Aggregate type	Coarse (9.5 mm to 50 mm)	Fine (0.3 mm to 9.5 mm)
Loss in weight (%) for crushed brick	10.9	4.1
Loss in weight (%) for cement mortar/concrete	65.9	38.5

Freezing and thawing resistance

Durability of concrete is defined as its ability to resist weathering action, chemical attack, abrasion, or any other process of deterioration. Among many factors the resistance of aggregate to cycles of freezing and thawing has noticeable effect. This test covers procedure for determining the loss in weight of aggregate produced by repeated freezing and thawing (AASHTO T103). After saturation, the sample must be fully immersed in water and placed in a freezing cabinet having a constant temperature not warmer than -23 C for 24 h after which removed and placed in the moist room having a constant temperature of 21 C for 24 h. This procedure constitutes one cycle. After the completion of the 10 cycles and washing and drying, the loss in weight of samples may be determined in the same manner as described above for soundness test. The results of the freezing and thawing test are gathered in Table 6.

Table 6. Freezing and thawing test results of crushed brick

Aggregate type	Loss in weight (%)
Coarse crushed brick (9.5 mm to 50 mm)	2.3
Fine crushed brick (0.3 mm to 9.5 mm)	12.6
Coarse crushed cement mortar/concrete (9.5 mm to 50 mm)	44.3
Fine crushed cement mortar/concrete (0.3 mm to 9.5 mm)	35.3

It can be seen that the loss in weight of recyclable materials is relatively high in comparison with natural aggregate, which is about 1 to 5 percent. This clearly indicates that these materials possess high porosity, easing the water passes and filling the voids more easily. When water freezing, it produces osmotic and hydraulic pressures in the capillaries and pores of aggregates causing the cavity dilates and ruptures. Considering the test results it is anticipated that the durability of concrete made with crushed brick shows better performance when subjected to freezing weather in compare with concrete made with crushed concrete/cement mortar.

Degradation of aggregates in the Los Angeles test

The Los Angeles test is designed to determine the ability of coarse aggregates smaller than 37.5 mm (1½ in.) to resist abrasion, using the Los Angeles Testing Machine in accordance with ASTM C131 (or AASHTO T96). Abrasion resistance is essential when the aggregates to be used in concrete or base and sub-base of pavement where subject to abrasion. In this test, a specified quantity of aggregates is placed in a steel drum containing steel balls, the drum is rotated, and the percentage of material worn away is measured. Specifications often set an upper limit on this weight loss. Table 7 gives the test results for crushed brick and concrete/cement mortar.

Table 7. Abrasive charge of materials in Los Angeles test

Aggregate type	**Abrasion (%)**
Crushed brick	49.6
Crushed concrete/cement mortar	46.5

The test results reveal that the resistance of recycled crushed brick to abrasion is relatively low in comparison with natural aggregate which is about 5 to 10 percent (Khaloo 1994) which possibly reduces the compressive strength of concrete made with such low quality aggregates.

MECHANICAL PROPRTIES OF CONCRETE MADE WITH CRUSHED CLAY BRICK

Successful application of recycled concrete as aggregate in concrete has been reported in some European and American countries, as reviewed by Desmyster & Vyncke (2000). While recycled concrete as aggregate has been used in large amounts the use of such low quality crushed brick is very limited. It should be noted that the clay bricks that are used in construction industry in Iran are produced in small and non-automated factories. This results in these clay bricks do not meeting standard specifications. This fact can be well understood when mechanical properties of brick aggregate are compared with natural aggregate (see Tables 2 to 7). Only a few researches have been devoted to study the properties of crushed bricks as aggregate and a few cases have been reported on the use of brick aggregate in concrete (Khaloo 1994). Even he has used the clinker brick of industrial waste of brick-producing kilns, which is defined as a very *hard-burned brick* with distorted or bloated shape and much higher strength in comparison with normal bricks taken from demolition waste and used in this study.

Here, the properties of concrete made with fine and coarse brick aggregates are studied. Following sections describe the properties of concrete made with three types of crushed brick aggregate in terms of size and material:

- A combination of fine and coarse crushed brick aggregate based on ASTM recommendation.
- A combination of fine crushed granite and coarse crushed brick aggregate based on ASTM recommendation.
- Just using fine crushed brick aggregate to produce fine aggregate concrete.

Using coarse and fine crushed brick as concrete aggregate

In order to produce brick aggregates for concrete, bricks taken from demolition of old building were crushing using a laboratory jaw crusher. Discharged brick aggregate was sieved according to ASTM C33 designation. Coarse aggregate were sized-screened to a maximum 19 mm. The fine grading must be within the fine aggregate zone specified by ASTM. The lower bound of this zone was selected since the grading of crushed aggregate in the laboratory jaw crusher was very close to this boundary.

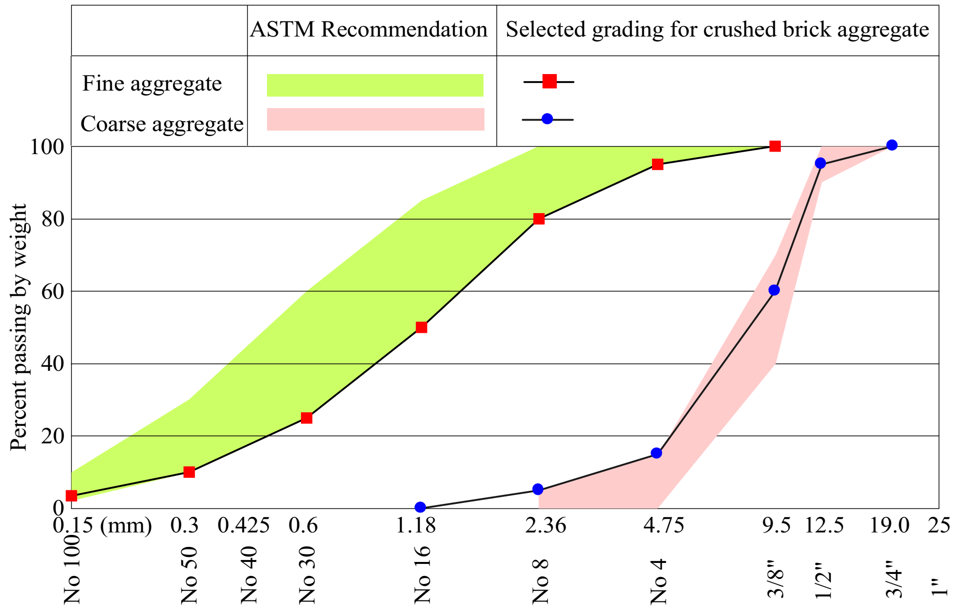

Figure 2. Fine and course aggregate grading according to ASTM C33

Figure 2 illustrates the selected grading of fine and coarse aggregate based on ASTM C 33. Before adding water, coarse and fine aggregates and cement were placed in the mixer and mixed for about 1 min. Then water was added gradually for a period of about of 2 min, and then the concrete was mixed for 3 minutes to produce a uniform mix.

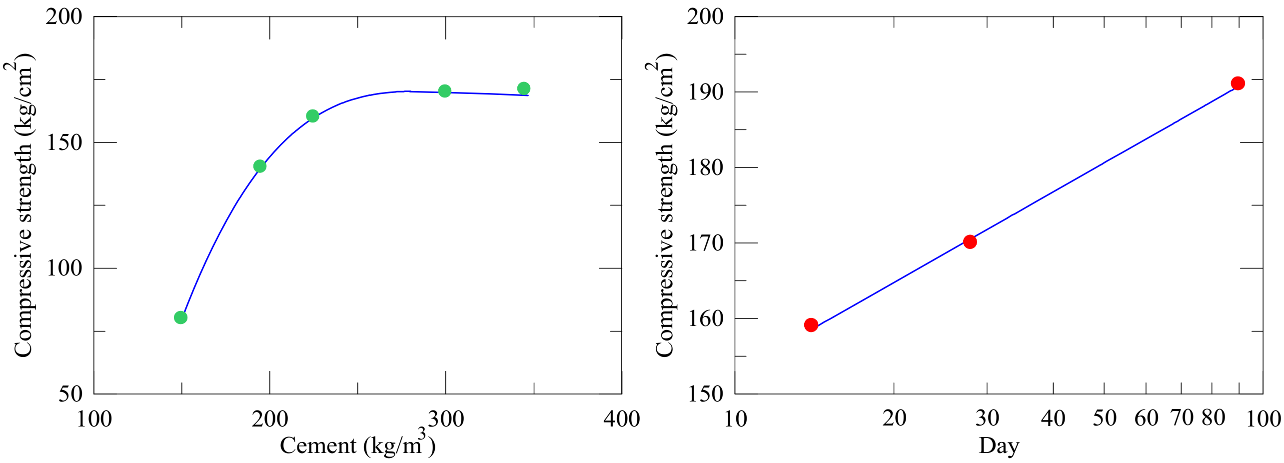

Figure 3. Compressive strength of concrete made with crushed brick as aggregate

A water cement ratio of w/c=0.5 was selected for different cement content (150-350 kg/m^3). The prescribed constant water ratio led to workability with slump varying from 40 mm to 90 mm respectively. The test results for different magnitudes of cement content, tested after 28 days, are depicted in Figure 3. As expected increasing of cement content causes an increase in strength up to a certain value, say around 250 kg/m^3, after which no significant increase is observed. It is thought that this is mainly due to the low strength of brick aggregates. Also included in this Figure is the strength growth with time for samples containing 220 kg/m^3 of cement.

Replacement of fine crushed granite with fine crushed brick

The second series tests involved replacement of fine crushed granite with fine crushed brick to increase the compressive strength. The grain size distribution was the same as for the first series (based on ASTM recommendation, see Figure 2). For comparison purpose samples with 100 percent granite were also prepared. The water cement ratio of w/c=0.5 and cement content of 350 kg/m^3 were selected. Table 8 gives the average compressive strength of samples with different aggregates.

Table 8. 28-day compressive strength of concrete made with different aggregates

Aggregate type	Average compressive strength after 28 days (kg/cm^2)
Fine and *coarse* aggregate from crushed *brick*	170
Fine aggregate from *granite* and *coarse* aggregate from crushed *brick*	255
Fine and *coarse* aggregate from crushed *granite*	450

It can be concluded that replacement of fine granite with fine crushed brick leads to an increase of about 50% in compressive strength.

Using fine crushed brick as concrete aggregate

As stated in the previous section to produce brick aggregates for concrete, masonry bricks must be crushed using an industrial jaw crusher. Experiences in this matter show that the production ratio of fine aggregate to coarse aggregate varied during the course of crushing and was about 2 to 3. In the other hand to produce moulded concrete bricks or blocks, fine aggregate could result in smoother surface bricks than coarse aggregate. For the last series, just fine crushed brick aggregates were used to examine the quality of concrete made with fine aggregate. The cubical moulds 2 inch (50 mm) in dimension were used for casting concrete for compression test. Two types of fine aggregate were used in this study.

- Fine aggregate was finer than 0.15 mm (100% passed sieve No. 100). The test results, which are shown in Figure 4, indicate that the compressive strength of concrete made with fine crushed aggregate is not high but acceptable if compared with bricks in original form. Considering the compressive strength of bricks in original form, which varies in the range of 30-70 kg/cm^2 (see Table 2), it can be seen that the strength of concrete bricks meet the ISIRI specifications and can be used in separator walls rather than main walls.

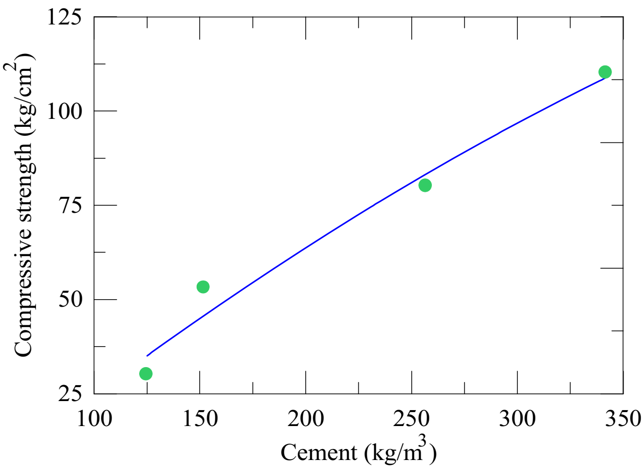

Figure 4. Compressive strength of concrete made with fine crushed brick (finer than 0.15 mm) as aggregate

- Fine aggregate was in accordance with fine aggregate recommended by ASTM (see Figure 2). The test results again are shown in Figure 5 indicate that the compressive strength of concrete made with fine crushed aggregate is higher than fine aggregate (previous part). The test results indicate that using fine aggregate (coarse sand size, see Figure 2) based on ASTM recommendation gives higher strength in comparison with the previous mix design. In this case, the strength obtained after 28 days is much higher than original bricks, implying that these concrete bricks can be used safely in new buildings.

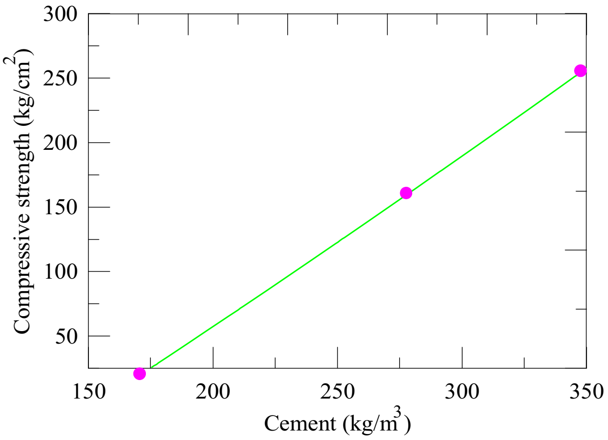

Figure 5. Compressive strength of concrete made with fine crushed brick (coarse sand size) as aggregate

STABILIZATION OF CRUSHED BRICK WITH CEMENT FOR USE AS ROAD MATERIALS

The main source of aggregate for use in road construction is crushed rock or natural aggregate. The increasing demands in natural aggregates for road construction encourages governments to recycle construction demolition waste as layer roads. To give satisfactory service a pavement must satisfy a number of structural criteria, among which the ability of subgrade to sustain traffic loading without excessive deformation is the most important (Powell et al, 1984). Recycled concrete or brick, however may not comply with the given requirements for use as road layer materials. The alternative method is the treatment of recycled materials to enhance their ability to perform their pavement function. As normally practiced, stabilization of soils by the use of additives is a remarkable process by which the addition of a few percent of a material such as lime, Portland cement or bitumen to a soil leads to disproportionably large increase in the bearing capacity of the soil (Ingles *et al*. 1972, Lay 1990).

The strength of stabilized soils can be evaluated in many ways, of which the most popular are the Unconfined Compressive Strength (UCS) test for cement-stabilized soils and California Bearing Ratio (CBR) for lime-stabilized soils (Sherwood 1993). These tests are most frequently used because of the relative ease with which they can be performed. In the current research, unconfined compressive test was used to evaluate the performance of improved recycled materials.

To investigate the efficiency of masonry bricks and concrete produced from demolition waste; recyclable materials were sieved on the sieve No 1 (25 mm opening size) to separate fine grains. The rubble and large pieces of bricks and concrete were crushed, using a jaw crusher, ready for grading. The grain size distribution, shown in Figure 6, is selected according to AASHTO T27 for use in sub-base and base construction.

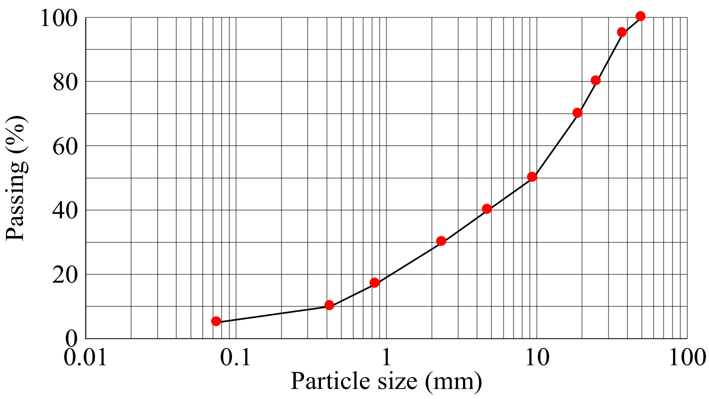

Figure 6. Grain size distribution of brick, cement mortar/concrete for base, and sub-base structure

Four different combinations of brick and cement mortar/concrete were prepared to investigate the strength of stabilized with different percent of Portland cement type II. The following is these tabulated combinations:

Table 9. Summary of geotechnical parameters

Combination code	Brick	Cement mortar/concrete
B85-C15	85 %	15 %
B70-C30	70 %	30 %
B55-C45	55 %	45 %

Regarding the grain size distribution shown in Figure 6, cement as a stabilizer agent is the best additive for improvement the soil properties. The optimum cement percent to be added to recycled materials is an experimental issue, which could be determined in laboratory. The researches in this field indicate that 3 to 7 percent cement adding to unbound aggregates results in minimum 2 MPa compressive strength, after 7 days for Portland cement type I and 11 days for type II (Sherwood 1993, Kosmatka & Panarese 1994). For the selected recycled material (Table 9 to 11), 3, 5, 7 and 9 percent cement was, therefore, added to examine the effects of cement dosage on compressive strength. To prepare samples, prescribed cement percent was added to unbound aggregate after which they were compacted to 100% compaction at optimum moisture content in compaction mould with 15 cm in diameter and height. The samples were left for 24 hours in laboratory temperature and were taken out from the mould after which were cured up to 11 days in a humidity and temperature controlled room. The unconfined compressive strength of samples for samples with different combination and various cement percent are gathered in Table 10 to 12.

Table 10. 11 day Compressive strength of samples containing 85% brick (combination code: B85-C15)

Cement percent (%)	Compressive strength (MPa)	Maximum dry density (g/cm^3)
3	3	1.58
5	4	1.66
7	6.2	1.59

Table 11. 11 day Compressive strength of samples containing 70% brick (combination code: B70-C30)

Cement percent (%)	Compressive strength (MPa)	Maximum dry density (g/cm^3)
3	3.8	1.69
5	4.4	1.65
7	5.2	1.67

Table 12. 11 day Compressive strength of samples containing 55% brick (combination code: B55-C45)

Cement percent (%)	Compressive strength (MPa)	Maximum dry density (g/cm^3)
3	4.2	1.72
5	4.9	1.74
7	6.2	1.73

Figure 7 depicts the unconfined compressive strength of samples whose test results are shown in Tables 9 to 11. It can be seen that with increasing cement percent the strength is increased as well. Depending on traffic, wheel load and type of the road services, different road and transportation standard codes recommend charts or values corresponding to UCS or CBR number and thickness of base and sub-grade course (e.g. Bowles 1992). Sherwood (1993) recommended a correlation between CBR number and UCS. This helps to evaluate the performance of material stabilized with cement or any other additives and tested in unconfined compression apparatus.

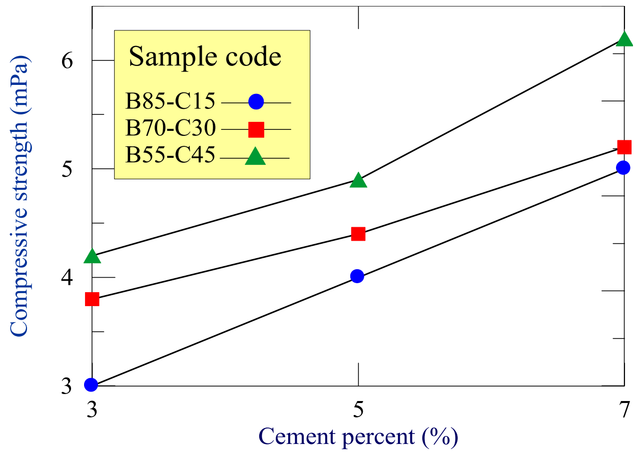

Figure 7. A plot of the variation of compressive strength with different percent of cement added for stabilization

Referring to Figure 7 the following comments can be drawn:

- With increasing cement percent the unconfined compressive increases
- With increasing recycled concrete percent (i.e. decreasing recycled brick percent) the unconfined compressive increases
- Stabilization of recycled materials by cement enhances the quality of such materials, which permits using these materials as base after treatment.

CONCLUIONS

The present research was an attempt to review the possibility of brick recycling and use as aggregate in concrete. The research led to the following conclusions:

- The primary test results indicate that the quality of such bricks is low in comparison with natural rocks. This is due to production process of such bricks in Iran, which is mainly different from European countries.
- The compressive strength of concrete made with crushed bricks is relatively low in comparison with ordinary concrete. However, concrete bricks produced with crushed bricks enjoy a level of strength higher than ordinary bricks; they could be used as bricks in new buildings.

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Corresponding author: Dr Jafar Bolouri Bazaz, Ferdowsi University of Mashhad, P O Box 91775-1111, Mashhad, Iran. Tel: +98 511 8437292. Email: bolouri@ferdowsi.um.ac.ir.

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