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Investigating the Properties of Asphalt Concrete Containing Recycled Brick Powder as Filler

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Abstract- One of the major problems caused by construction and demolition of buildings is the environmental pollution due to the disposal of the large volume of generated waste materials. Therefore, in addition to the protection of environment, the recycling and reusing of the waste materials is an economical measure. One of the applications of the waste materials is for highway construction. In this research, the viability of using the recycled brick powder as a partial or full replacement of mineral filler in asphalt concrete has been investigated. The primary natural siliceous aggregate filler, as control filler, has been replaced in different percentages (25, 50, 75 and 100%), with the secondary recycled brick powder, and the mixtures have been evaluated in terms of, Marshal Stability, flow, indirect tensile strength, moisture damage and volumetric characteristics. The results show that, the Marshal Stability increases and the flow decreases with increasing the brick powder content in the mixture. The results show that full replacement of the natural filler with brick powder, results in the highest resistance against permanent deformation and indirect tensile strength. It is also shown than the mixtures containing brick powder are more resistant against moisture damage than the control mixture. The replacement of the mineral filler with the brick powder does not significantly affect the volumetric properties of the mixture.

Keywords- *filler, brick powder, asphalt concrete, tensile strength, moisture damage*

I. INTRODUCTION

The ever increasing volume of solid waste materials has become a major environmental problem of communities. A good management of these waste materials is necessary for enhancing the life quality. The major fraction of solid wastes is the construction and demolition waste (CDW) materials. Based on the municipality report, at present, 50000 tons of CDW materials is daily generated in Tehran, which is about 5 times higher than the rest of municipal wastes. The large quantities of construction and demolition wastes (CDW) have resulted from increasing construction, renovation and demolition activities, and infrastructure development projects. The huge amount of CDW materials causes harmful effects on the environment if they are not properly managed. The environmental problems include diminishing landfill spaces due to incremental quantities of disposed wastes, depleting construction materials, raising the contamination from landfills that lead to serious negative health effects, damage to the environment and the increase of energy consumption for transportation and manufacturing new materials instead of those dumped in landfills. CDW, also contribute into the phenomenon of global warming. The current practice in Iran and many other developing countries is disposing the majority of CDW materials and occupying the valuable landfills. Finding an application for the CDW materials is financially and environmentally beneficial. As highway construction consumes a large amount of raw materials and energy, it has been considered as an alternative for using the CDW materials. The use of CDW materials in highway construction can preserve natural resources, and reduce environmental pollution as otherwise virgin materials should be taken from natural resources, and their processing, production and transportation consumes a large amount of energy. The CDW materials can be used in different layers of pavement structure, such as base, sub-base and surface course. The viability of using CDW materials in highway construction has been mainly investigated for lower layers of pavement [1-5]. However, the use of CDW materials in asphalt has not been sufficiently investigated.

Different materials can be found in CDW materials; however, brick and cement concrete constitute the major fraction of the materials [6Li, 2008]. Bricks make up the major structural elements of most of the buildings which are currently demolished in Iran. In addition, it is reported that about 7000 brick production plants in Iran, produce about 50 million tons of brick each year. As the average life of buildings in Iran is estimated to be 30 years, a large volume of waste bricks will be generated in future. The application of crushed brick as concrete aggregate has been investigated by a number of researchers, which, found that the composition of crushed brick largely influences the mechanical properties of concrete [7-9]. It has been found that the concrete containing crushed brick has a lower flexural, tensile and compressive strength, modulus of elasticity and thermal conductivity, and a higher shrinkage, water absorption, fire resistance and abrasion resistance [9]. The use of crushed brick, as a substitution of the natural aggregates in unbound and cement stabilized base and sub-base layers have also been investigated [3, 10, 1, 4].

Almost all of the highways in Iran are paved with asphalt concrete. An estimation of 100 million tons of hot mix asphalt concrete is produced and placed in pavements every year in Iran. Production of this amount of asphalt concrete consumes about 95 million tons of aggregates, which almost all of these aggregates are extracted from natural resources. Khalaf [11] investigated the possibility of using crushed clay bricks as coarse aggregates in bituminous mixtures. It was found that the mixtures containing crushed brick outperformed the mixtures containing the primary granite aggregates. This was attributed to the high porosity and the roughness of the surface of crushed clay brick aggregates. About 5-10% of the weight of total aggregate in asphalt concrete is filler. A certain amount of filler is necessary in asphaltic mixtures to obtain the required density and strength. The filler particles fill a portion of the space between sand and gravel particles, and thus contribute to increase density and strength. The physico-chemical properties of the filler particles influence significantly the performance of the asphaltic mixtures. The materials used as filler must met the required specifications. The use of various waste materials, such as fly ash, waste lime, cement pass dust and recycled concrete powder, to replace the mineral filler in asphaltic mixtures, have been investigated [12-16]. It has been found that these waste materials can improve the engineering properties of asphaltic mixtures, and, at least have no negative influence on the properties. Chen et al. [15] compared the properties of an asphaltic mixture containing brick powder with those of an asphaltic mixture containing mineral limestone filler, and resulted that the mixture containing brick powder performed better than the other in terms of creep, fatigue, stiffness and water sensitivity.

In this research, some engineering properties of asphaltic mixtures, which a fraction or all of their primary siliceous filler has been replaced with brick powder, have been investigated, to find the optimum replacement rate. Different percentages of the primary natural aggregate filler has been replaced with the brick powder and the Marshal Stability, flow, volumetric properties, indirect tensile strength and moisture damage properties have been investigated.

II. MATERIALS

The materials used in this research include asphalt cement, aggregates and brick powder. The asphalt cement used in this research was 60/70 penetration grade bitumen supplied by Tabriz refinery. Table 1 shows the properties of the bitumen used in this research for making specimens. Siliceous aggregate has been used, which were provided by Zanjan Rahsaz asphalt plant. Aggregates were delivered at four different sizes of 12-19, 6-12, 0-6mm and filler. Based on the gradation of each fraction, and by selecting No. 4 gradation in Iranian National code for asphalt concrete of binder and wearing course, the percentage of each fraction was calculated, by setting the average of upper and lower limits as the target gradation. Figure 1 shows the upper and lower limits of the code gradation, and the gradation of the mixture used in this research. The physical properties such as toughness, soundness, angularity, cleanness, flat and elongated particles, specific density and the water absorption of the coarse and fine aggregates and filler were also measured, to control meeting the required specification and using in mix design process. Table 2 shows the properties of the fine and course aggregates used in this research.

TABLE I. SPECIFICATIONS OF THE BITUMEN USED IN THIS RESEARCH

Test	Standard	Results
Density in 15˚C	ASTM-D70	1.016
Penetration in 25˚C (0.1mm)	ASTM-D5	66
Softening Point (˚C)	ASTM-D36	49.1
Ductility in 25˚C (cm)	ASTM-D113	150
Solubility in Trichloroethylene %	ASTM-D2042	99.8
Flash Point (˚C)	ASTM-D92	298
Loss in weight after thin film oven test %	ASTM-D1754	0.03
Retained penetration after thin film oven test %	-	98
Ductility after thin film oven test (cm)	-	94

TABLE II. AGGREGATE PROPERTIES

Properties (tests) / Materials	Sand Equivalent% ASTM-D2419	Los Angeles Abrasion Test ASTM-C131	Plasticity Index AASTM-D4318	Angularity in two sides % ASTM-D5821	Moisture Absorption %	Density ASTM-C127,128 ,D854	Flakiness BS 812	Loss in Magnesium Sulfate Solution % ASTM-C88
Coarse aggregate	-	21	-	85	1.6	2.607	12	1
Fine aggregate	53	-	N.P	-	2	2.593	-	1
Filler	-	-	N.P	-	-	2.75	-	-

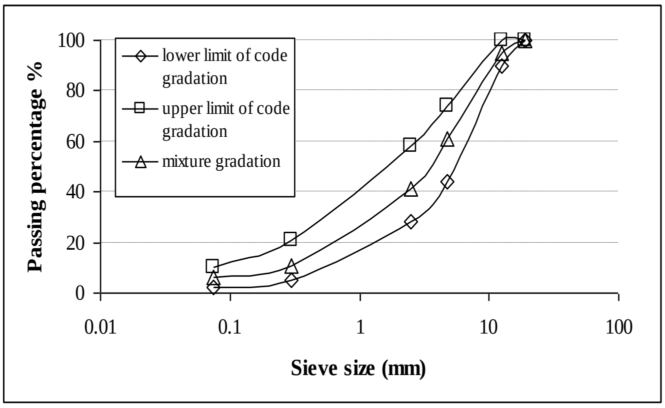

Figure 1. Gradation of the mixture aggregates

The brick powder was obtained from waste clayey bricks taken from a demolished building in Zanjan. The bricks were washed from the adhered mud and mortar, and then were dried at 80˚C for 10 hours. Then, the dried bricks were crushed by a laboratory crusher and grounded using a ball mill for 15 minutes to brick powder (Figure 2). The gradation, specific gravity, absorption and specific surface area of both the brick powder and control siliceous filler were measured, which the results are shown in Table 3. Also, the drain down test was conducted according to AASHTO T-305, on the mixtures made by each filler, separately. The drainage value, which is an indication of the free bitumen content in the mixture, for the brick powder and the control filler was determined to be 0.15 and 0.33%, showing that the brick powder has higher bitumen absorption. Previous research measured the microscopic morphology of brick powder and limestone filler by Scanning Electronic Microscopy (SEM) and showed that brick powder particles are much rougher than the natural limestone aggregate filler with more homogeneous particles distribution, indicating that the brick powder has more absorption than the limestone filler [15].

Figure 2. Brick powder used in this research

TABLE III. PHYSICAL PROPERTIES OF FILLERS

property		Brick powder	Siliceous filler
Passing %	1.16mm	100	100
	0.6	100	100
	0.3	96	98
	0.075	80	89
Specific gravity (gr/cm^3)		2.69	2.75
Specific surface area (cm^2/gr)		463	353
Absorption %		1.2%	0.8%

III. EXPERIMENTAL WORK PLAN

In this research, using the same aggregate source and gradation, and asphalt cement, the effects of replacing different percentages of the primary siliceous filler with the brick powder on the Marshal Stability, flow, volumetric properties, indirect tensile strength and moisture damage of a typical wearing course asphalt concrete have been investigated. The natural aggregate filler was replaced at 4 incremental percentages of 25, 50, 75 and 100% (by weight) with the bricks powder, and the properties of the mixtures were compared with the control mixture with 100% of natural filler.

IV. MIX DESIGN AND SPECIMEN FABRICATION

The Marshal mix design method, according to ASTM D1559, was utilized to find the optimum asphalt content. The mix design was done for the mixture with the mineral natural filler, for which the optimum asphalt content was determined to be 5.2%. The rest of mixtures were made with the same asphalt content. Cylindrical specimens, 100mm in diameter and about 65mm in height were fabricated using Marshal set up. The required amount of each fraction of aggregate, including filler, and bitumen were weighed. Based on the desired percentage of mineral filler replacement, the weight of required brick powder was calculated and substituted the natural filler. The mixed aggregate of each mixture was heated in oven at 172˚C for 4 hours, and the asphalt cement was heated at 150˚C. The heated aggregates and asphalt cement were mixed by laboratory mixer, after which, the mixture was placed in the Marshal Compactor mold and compacted by the automatic compacter set at 75 blows for heavy traffic. After 24 hours, the specimens were removed from the mold and used for the desired testing.

V. EXPERIMENTS

A. *Marshall tests*

The Marshal test was conducted on the specimens of each mixture, according to ASTM D1559. The specimens were placed in a water tank set at 60˚C for 30 minutes, after which were loaded using the Marshal test set up, at a constant rate of 50.8mm/min, and the force required for breaking the specimen was measured as the Marshal Stability, and the diametrical deformation of the specimen at failure was measured as flow. The Marshal Quotient was calculated by dividing the Marshal

Stability to the flow, which is usually used as an indicator for the strength against permanent deformation.

Before doing the Marshal tests, the bulk density of the compacted mixtures was measured according to ASTM D2726 standard method. The maximum theoretical density of the mixtures was also measured according to ASTM D2041 standard method. Using the bulk and the maximum theoretical density of the mixtures, and other required data, the air voids content of the mixtures (V_a), the voids in mineral aggregates (VMA), and the voids filled with asphalt (VFA), were determined using the Equations presented in Asphalt Institute Manual [17Asphalt Institute, 1997].

B. Indirect tensile strength tests

The indirect tensile strength tests were conducted at 25 and 40˚C according to the ASTM D6931 standard method. The specimens were immersed in water tank set at the desired temperature for 30 minutes, after which placed in ITS frame and loaded diametrically by marshal test set up at a rate of 50.8mm/min until failure. The required force for breaking the specimen was measured and the indirect tensile strength was calculated using Equation (1).

$$S_t = \frac{2000P}{\pi t D} \qquad (1)$$

In which, S_t is the indirect tensile strength in kPa, P is the maximum applied load for breaking the specimen in N, D is the specimen diameter in mm, and t is the thickness of specimen in mm.

Using the ITS frame and Marshal set up loading frame, the moisture damage property of the mixtures was evaluated according to ASTM D4867 standard method. According to this standard, the air voids content of the mixtures utilized for moisture damage evaluation, must be in the range of 6 to 7%. Therefore, the number of blows of Marshal Compactor was adjusted by try and error to achieve the desired air voids content. The specimens were divided into two groups. The specimens in one group were saturated at 55 to 80% of their air voids, by placing them in water and using vacuum pump. Then, they were placed in a water bath set at 60˚C for 24 hours, and, then, in a water bath set at 25˚C for one hour, before conducting the indirect tensile test. The specimens of this group are denoted by wet conditioned specimens. For the specimens in the other group, which are denoted by dry conditioned specimens, the indirect tensile test was conducted after placing them in the water bath set at 25˚C for 30 minutes.

For each mixture, the indirect tensile strength of the wet and dry conditioned specimens were measured, and the tensile strength ratio (TSR), which is used as a criterion for evaluating the moisture damage potential of asphaltic mixtures, was calculated using Equation (2).

$$TSR = \frac{S_{tm}}{S_{td}} \times 100 \qquad (2)$$

Where, $\boldsymbol{S_{tm}}$ is the indirect tensile strength of the conditioned specimen, and $\boldsymbol{S_{td}}$ is the indirect tensile strength of the dry specimen.

VI. TESTS RESULTS AND DISCUSSIONS

A. Marshall tests results

Figure 3 shows the variation of the Marshal Stability with the percentage of natural filler replacement with brick powder. As can be seen, the Marshal Stability of the mixtures containing brick powder is higher than the control mixture, with the highest Marshal Stability for the mixture with 25% of brick powder. The increase of the marshal stability of the mixtures containing brick powder is attributed to the rough surface of the brick particles and higher bitumen absorption. Figure 4 shows the variation of the flow with the percentage of natural filler replaced with brick powder. As can be seen, the flow decreases with increasing the brick powder content in the mixture, indicating that the resistance against permanent deformation increases with increasing the percentage of brick powder in the mixture. Although the reduction of flow is not always favorable, as it could lead to fracture at low temperature, however, the flow of all the mixtures exceeds the minimum value specified by the specification, which is 2mm. Figure 5 shows the Marshal Quotient of the mixtures containing different glass powder contents. Marshal Quotient is the ratio of the Marshal Stability to the flow, and is used as an indication of the mixture stiffness and resistance against permanent deformation. As can be seen, the Marshal Quotient increases with increasing the brick powder content. Therefore, in terms of resistance against permanent deformation and stiffness, the optimum mixture is the mixture containing 100% of brick powder.

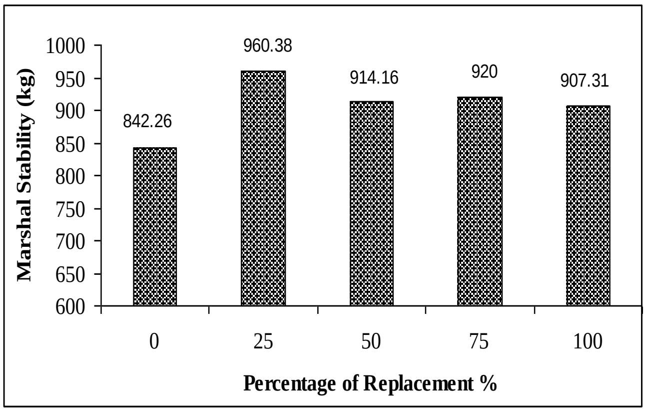

Figure 3. Variation of Marshal stability with brick powder content

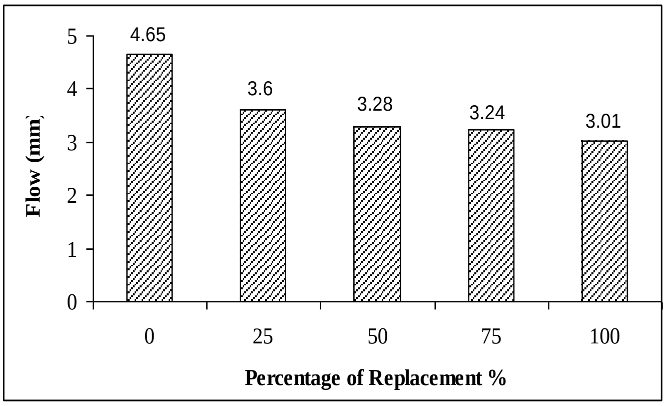

Figure 4. Variation of flow with brick powder content

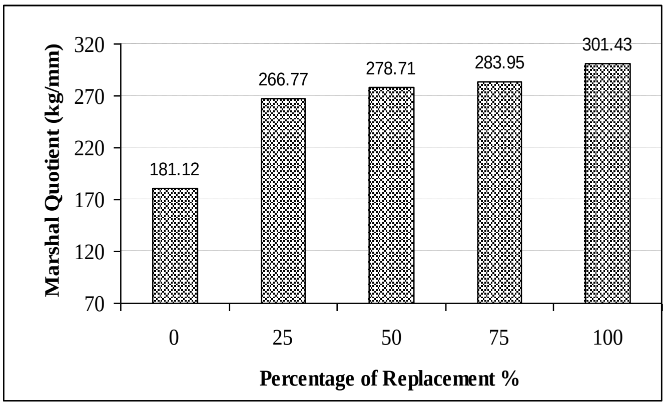

Figure 5. Variation of Marshal Quotient with brick powder content

B. *Volumetric properties*

Air voids content of compacted mixture, voids in mineral aggregates (VMA), and the voids filled with asphalt (VFA) are the three important volumetric properties of asphalt concrete which considerably affect the performance of the mixture, and are considered in the mix design process to satisfy the limitations specified by the codes. Figures 6, 7 and 8 show, respectively, the variation of the air voids content, VMA and VFA with the percentages of the primary filler replaced with brick powder. As can be seen in Figure 6, the air voids content of the mixtures is not significantly influenced by the brick powder content of the mixture. This is attributed to the lower density of the glass powder compared with the primary filler. The air voids content of all the mixtures lies within the limited range of 3 to 5% specified by Iranian asphalt pavement code for the wearing and binder course of pavements. As can be seen in Figure 7, although the difference is marginal, the VMA of the mixture with 25% of brick powder is minimal and still higher than the minimum value limited by specification, which is 14%. Figure 8 shows that the VFA is not significantly affected by the brick powder content, and, at the optimum bitumen content of the control mixture, the VFA value of all the mixtures is higher than the allowable minimum values, which are 60, 65 and 70, for, high, medium and low traffic, respectively, and less than the allowable maximum value, which are 75, 78 and 80, for high, medium and low traffic, respectively.

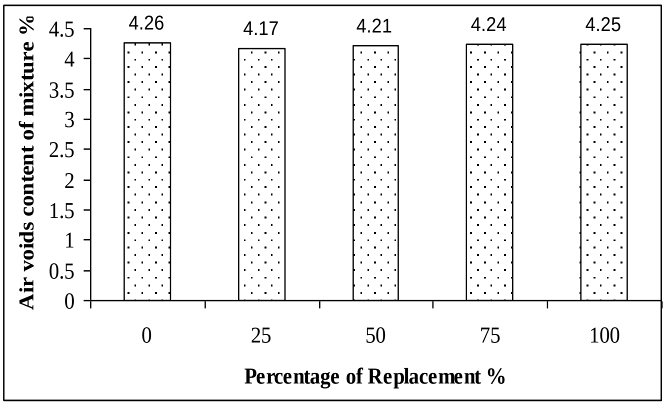

Figure 6. Variation air voids content of mixture with brick powder content

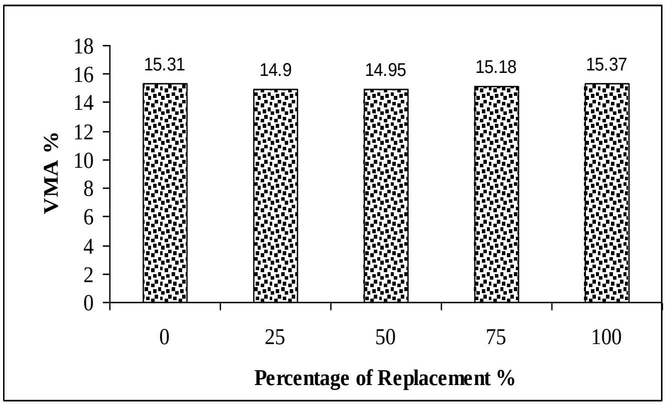

Figure 7. Variation of VMA with brick powder content

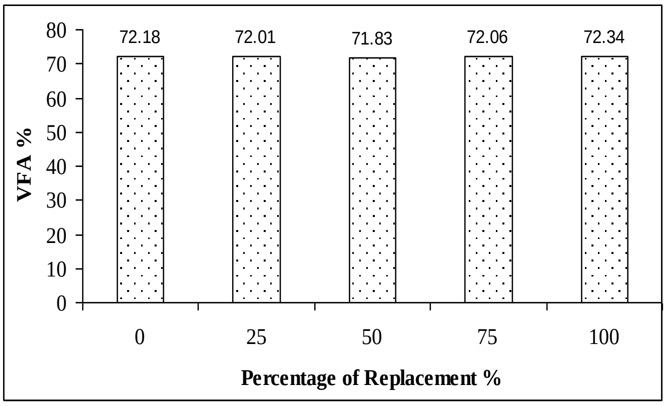

Figure 8. Variation of VFA with brick powder content

C. *Indirect Tensile Strength*

Figure 9 shows the indirect tensile strength of the mixtures containing different percentages of brick powder at 25 and 40˚C. As can be seen, at both temperatures, the indirect tensile strength increases with increasing the brick powder content of the mixture. The highest tensile strength is achieved by fully replacement of the mineral fill with brick powder. This is attributed to the rough surface of brick powder particles and more bitumen absorption. However, the effect of improving the tensile strength at 25˚C is higher than that at 40˚C. The indirect tensile strength of the mixture containing 100% of brick powder at 25 and 40˚C, is, respectively, 27% and 17% higher than that of the control. This is beneficial for fatigue cracking, as the critical temperatures for fatigue cracking are the intermediate temperatures and the higher the indirect tensile strength results in a higher fatigue life [18].

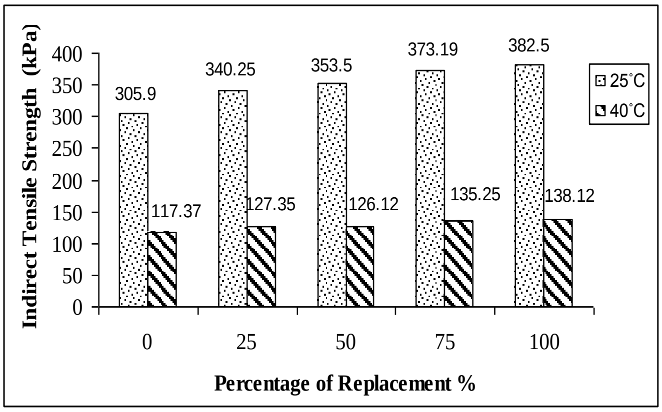

Figure 9. Variation of Indirect tensile strength with brick powder content

In order to investigate the moisture damage potential of the mixtures containing different percentages of brick powder, the indirect tensile strength of the mixtures has been measured at two different conditions, as described in Section 2.6. Figure 10 shows the indirect tensile strength of the wet and dry conditioned mixtures. As can be seen, at the comparable temperature of 25˚C, the indirect tensile strength of the dry conditioned mixtures is lower than that presented in Figure 9, which is attributed to the higher air voids content of the mixtures tested for moisture damage. Also, trend of the variation of the indirect tensile strength at both conditions is similar, with the peak indirect tensile strength for the mixtures containing 100% of glass powder, which are also similar to the results presented in Figure 9. The ratio of the indirect tensile strength of the wet conditioned to that of the dry conditioned mixtures is denoted by TSR, which is used as an indication of the moisture damage potential of asphaltic mixtures. The variation of TSR with the percentage of brick powder in the mixture is shown in Figure 11. As can be seen, the TSR of the mixtures containing brick powder is higher than that of the control mixture, showing more resistance against moisture damage for the mixtures containing brick powder. According to the Iranian asphalt pavement code, the minimum TSR of the mixtures is 80%. Therefore all the mixtures met the requirements of the specification.

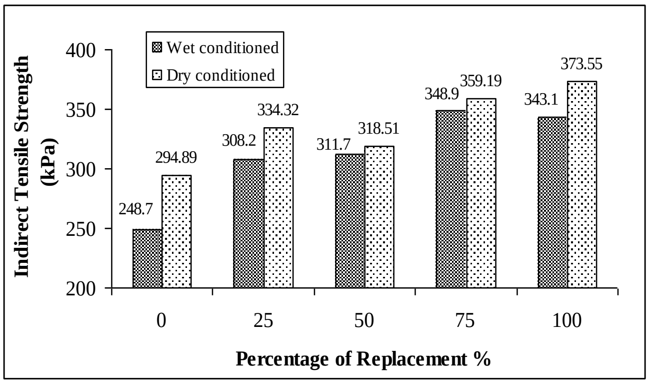

Figure 10. Variation of indirect tensile strength of with brick powder content

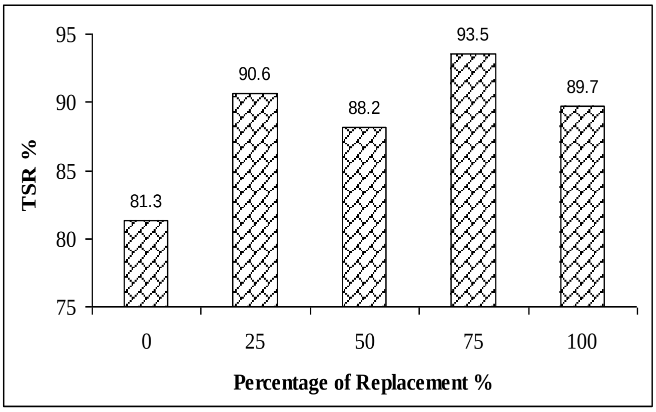

Figure 11. Variation of VFA with brick powder content

VII. CONCLUSIONS

In this research, the mineral filler of an asphalt concrete has been replaced with brick powder at different proportions, and some engineering properties have been investigated. The following results can be drawn from this research.

- The Marshal Stability and the Marshal Quotient of the mixture increases with increasing the replacement proportion of the mineral filler with brick powder.
- The resistance against deformation of the mixtures increases with increasing percentage of mineral filler replaced with brick powder.
- Replacing the mineral filler with brick powder does not significantly influence the air voids content, voids in mineral aggregate and the voids filled with asphalt.
- The indirect tensile strength of the mixture increases with increasing the percentage of replacement of mineral filler with brick powder.
- The effect of increasing the indirect tensile strength of mixture by incorporating the brick powder is higher at intermediate temperatures.

- The moisture damage resistance of the mixtures containing brick powder is higher than that of the control mixture with mineral filler.
- This research shows that full replacement of mineral filler with brick powder in environmentally and financially beneficial.

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