Use of Processed Tear-off Roof Shingles to Improve Performance of Roadbase Materials

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ABSTRACT

This paper presents the results of a research project that focused on evaluating the potential use of processed tear-off shingles in road works. The project was conducted in attempts to promote construction sustainability through recycling more construction wastes into roads. The targeted applications were road base and unpaved gravel roads. Two different sizes of tear-off shingles were investigated: ground shingles with 100% of the particles passing sieve 4.75 mm and processed shingles with a maximum size of 75 mm and 40% passing 4.75 mm. Petrogrpahic examination confirmed that the investigated shingles did not contain asbestos. Five types of granular materials were investigated to determine the type of material that benefits the most from using the shingles. The five types of materials were quarried crushed limestone, crushed natural gravel with 72% crushed particles, and three recycled concrete aggregates (RCA).

California Bearing Ratio (CBR) results showed that ground shingles provided better results compared to processed shingles. The use of an optimum amount of shingles (5%) increased the stability of the granular materials. This was the case for two of the RCAs and the natural gravel material investigated in this study. On the other hand, one of the tested RCA and the crushed limestone were adversely affected by the addition of shingles. The response of a granular material to shingle modification was found to be related to the amount and quality of fines in the materials. In terms of permeability, the addition of shingles did not have a significant impact on the drainage characteristics of the tested materials.

INTRODUCTION

About 1.25 million tons of scrap asphalt shingles and asphalt saturated roofing felt are generated every year from Canadian residential re-roofing operations and other construction activities [1]. The annual amount generated in the US is 11 million tons that is produced, mostly, from the building renovation and demolition, and shingle manufactures [2]. Only 5% of shingle waste is recycled in new construction [3]. Currently, the most common disposal method for asphalt shingles in the US is land filling [4,5]

One of the common concerns regarding the reuse of Recycled Asphalt Shingle (RAS) is the presence of asbestos. Asbestos was used for the manufacturing of shingle in the past; however, the occurrence of asbestos-contaminated tear-off shingle samples has been reported to be very low [6]. Indeed, the Iowa Department of Transportation (IDOT) tested 368 samples from 1994 to 1997 and only 0.8% of the samples (3 samples) were found to contain asbestos [6]. Similarly, no asbestos-contaminated shingle sample was found when 2000 samples were tested in 2001. Since 2004, only 1.67% of the tested samples were found to contain asbestos out of over 750 samples [6]. Data available for 27,694 samples collected from Maine, Iowa, Florida, Missouri, Minnesota, and Massachusetts showed that asbestos was detected in approximately 1.53% of the samples [2].

Bituminous shingles contain approximately 30% asphalt cement binder [7] which makes shingles an attractive candidate for recycling. The potential uses of recycled waste asphalt shingles include hot mix asphalt (HMA) and cold asphalt patching, roadways as dust control for rural roads, and fuel in cement kilns [2].

There is a potential for use of asphalt shingles in the aggregate bases used in rural roads. In addition to saving landfill space, such shingle uses can lead to minimizing dust, reducing vehicle noise, and requiring less road maintenance [7,8,. The Iowa Department of transportation looked at the viability of using asphalt shingles as a dust control material on a rural Benton County granular surfaced roadway. The ground shingles proved to be effective in minimizing dust [6] extending service life, and reducing the frequency of maintenance [7].

Recycled concrete aggregates (RCA) account for about 5% of the total aggregates market. It is estimated that 85% of all RCA is used as road base due to its availability, low transport cost, and good physical properties [9]. RCA has a rougher surface texture than natural aggregate [10]. In many applications, recycled aggregates are superior to natural aggregate for use as a granular base [9].

This paper presents the preliminary results from a research project that focuses on investigating the potential use of tear-off shingles to improve the properties of granular materials with emphases on RCA. Combining the two construction by-products (shingles and RCA) is a step towards construction sustainability in Ontario and North America in general. The paper consists of five sections. The first section presents a summary of the basic properties of RCA based on the literature. The second section presents the experimental program. The third and fourth sections present the results of the investigation and a general discussion of the stability results. The final section presents concluding remarks.

LITERATURE-BASED RCA PROPERTIES

The coefficient of permeability of crushed limestone samples with specific surface area of the fine fraction (Ssf) of 11.4 m²/g was found to be in the range of 4.9×10^{-9} to 7.0×10^{-8} m/s. The coefficient of permeability for crushed limestone was 1.1×10^{-6} m/s for a sample with unknown specific surface area of the fine fraction [10]. The hydraulic conductivity as evaluated by the coefficient of permeability increases as the porosity increases and the fine content decreases. The hydraulic conductivity of crushed aggregate also depends on the mineralogy of the material. Crushed granite samples showed the highest values of porosity and hydraulic conductivity whereas crushed limestone samples had the lowest values among crushed granite, crushed shale and crushed limestone [10].

The strength of compacted RCA increases over time due to the RCA's self-cementing properties which is believed to be controlled by the properties of the fine portion of the RCA (<5 mm). The size fractions <0.15 and 0.3–0.6 mm (active fractions) were found to be the principal cause of the self-cementing properties of the fine RCA [11]. In terms of the California Bearing Ratio (CBR), it was found [12] that for samples prepared at optimum moisture content and soaked for 9 hours, the CBR value at 0.2″ penetration exceeded that at 0.1″ penetration. The maximum CBR was obtained when the material contained 8% non-plastic fines [12].

RCA produced from high strength concrete was found to have higher Los Angles (LA) abrasion than some virgin aggregates [13]. In addition, the absorption of RCA was reported to be higher than that of the natural aggregates while the relative density of the natural aggregates was higher [13].

The cost of processing RCA for use as granular base may be greater than the cost of processing natural aggregate due to relatively small quantities involved and the labor-intensive nature of the operations like removing reinforced steel. However, there is still a net saving when RCA is used in lieu of natural aggregates. A study in Ontario found that RCA used in urban areas results in 5–10% savings due to reduced transportation costs and absence of tipping fees. The reduced transportation cost of RCA is attributable to its lower specific gravity which reduces truck transportation costs compared with hauling natural aggregate [14].

EXPERIMENTAL PROGRAM

Three types of RCA were used in this study. The sieve analyses of the samples are shown in Figure 1. The three samples contained minor amounts of bricks and Reclaimed Asphalt Pavement (RAP). The three RCA samples are labelled RCA 1, RCA 2 and RCA 3. In addition, crushed limestone and crushed gravel material, with 72% crushed particles [15], were also investigated in this study. Table 1 shows the sand (passing 4.75-mm sieve) and fines (passing 75 µm sieve) fractions of the three types of RCA and the two natural granular materials. Table 1 also includes the micro-Deval percent loss of the investigated five materials. This test [16] was conducted on the coarse fraction of the materials (between 19.5 mm and 13.2 mm).

Two types of processed shingles were used – the difference being the grain size distribution as shown in Figure 2. The processed shingle was tested for asbestos content and was found to be asbestos-free. The two types of shingles were labelled Processed and Ground Shingles. It should be noted that the processed shingle is obtained by processing the waste or tear-off shingles to remove nails and undesirable materials, and to break it into a smaller size as shown in Figure 2. The ground shingle was obtained by further grinding the processed shingles to obtain sand-size gradation as shown in Figure 2.

The effects of using shingles on the stability of the three types of granular material (RCA, crushed gravel, and crushed limestone) were evaluated using the CBR test [17]. The test was conducted on samples that are compacted at their optimum moisture contents (OMC) and maximum dry density which were determined using the modified proctor test [18]. Since the absorption of RCA is high, the OMC values were determined by keeping the aggregate with the moisture for 24 hours to avoid any fluctuation in the determined OMC. The effects of adding shingles on permeability were also evaluated using the constant head test [19].

RESULTS AND DISCUSSION

Effect of Shingle Content on Maximum Dry Density and OMC

The results of maximum dry density and OMC are listed in Table 2. It is clear from the Table that the maximum density decreases with the addition of ground shingles. This is likely to be attributable to the lower density of shingles. For each of the tested granular materials, the addition of shingles did not result in a considerable change in the optimum moisture content.

Effect of Shingle Content and Size on Stability

The effects of shingle content and size on the stability (CBR) of RCA 1 and RCA 2 are shown in Figure 3. It is clear from the graph that ground shingles result in better stability compared to processed shingles. One of the reasons behind this finding could be that the large-size shingle particles act as a slippage surface and reduce the stability. On the other hand, shingles of small size was distributed homogeneously within the sample and provided some binding to the particles, especially those of sand and silt size. Based on the results presented in Figure 3, it was decided that ground shingles is more suitable for enhancing the stability of granular materials. Ground shingles were then used in the rest of the experimental program.

The effect of shingle content on the CBR of the three types of RCA is shown in Figure 4. This shows that different RCA's respond differently to the addition of shingle. Ground shingles were found to enhance the stability of RCA of low CBR as the case with RCA 1. This granular material has a relatively low CBR (around 60%). The stability increased by the addition of shingles up to 10% with the optimum improvement at 5%. The stability of RCA 2 which had a higher CBR than RCA 1 was found to improve by the addition of 5% shingles. At 10% shingles, however, the CBR value declined. RCA 3 which showed the highest CBR was found to be negatively affected by the addition of any amount of shingles.

The effect of adding shingles to natural granular materials is illustrated in Figure 5. The addition of shingles to crushed limestone (with original CBR value of 140%) decreased the stability. For crushed gravel, however, the addition of shingle up to 5% slightly enhanced the stability.

The results presented in Figures 3-5 show that the capacity of shingles to enhance the stability of granular materials depends on the properties of the materials. The use of shingles enhanced the stability of materials that have a relatively low CBR, but had negative effects on materials with high CBR. This can be explained, at least partly, based on the binding effect of the shingles. This effect is probably at an optimum with fines that are non-angular. Figure 6 shows the effects of shingles on the stability of fine-grained soil with maximum size of 2.36 mm and 5% passing 75µm sieve. The graph shows that the 5% shingle content resulted in a significant improvement in the stability of this material. The optimum improvement was obtained at the 10% shingle content; however, even 20% resulted in stability higher than that of the original material without shingles.

Effect of Curing on Stability of Shingle-Modified Granular Materials

Since road construction in Canada usually takes place during spring and summer, it is imperative to investigate the role of the construction temperature on the shingle-modified granular materials. RCA 2 and RCA 3 were selected for this investigation. RCA 2 was mixed at the optimum moisture content with ground shingles, placed in plastic bags, and stored at 38°C for 24 hours. After the 24 hours, the mixed materials were compacted, left in the air for 7 days and then tested for CBR. The results are shown in Figure 7 which shows that the curing regime resulted in higher CBR values. However, the curve of the CBR after curing versus shingle content was more or less parallel to that of the materials when tested just after compaction. This shows that the curing did not have much effect on the performance of the shingles, since the CBR of the RCA 2 with no shingle did also improve as a result of the curing. The increase in stability is probably a result of drying and/or some self cementing properties of the RCA.

Figure 8 shows the effect of curing on shingle-modified RCA 3. In this case, two different curing regimes were investigated. The first regime involved compacting and leaving the compacted samples in the air for 3 days. The other regime involved packing the loose mixtures of RCA 3, shingles and optimum moisture in thick plastic bags, and maintaining the bags with the samples for 4 hours in a heat room at 38 °C. Then, the mixtures were removed from the heat room, compacted and left in air for 3 days. As shown in Figure 8, both regimes resulted in similar CBR values which indicated that mixing at a temperature of 38°C did not have a noticeable effect on the capacity of shingles to stabilize RCA.

Effect of Addition of Shingles on Permeability

The effect of shingles on permeability of granular materials was investigated using RCA 2 and crushed limestone. The permeability was evaluated using the constant head test described in MTO LS- 709 and the results are shown in Figure 9. Coefficient of permeability of RCA 2 was found to slightly decrease with increase in shingle content. The permeability of the crushed limestone was significantly decreased with the addition of 5% shingle followed by a relatively slight decrease at a shingle content of 10%. However, all the obtained values of coefficients of permeability were within the range recommended by the Ministry of Transportation of Ontario [20] for granular materials (10^{-4} to 10^{-8} m/sec.). This shows that the addition of shingles to granular materials does not jeopardize the drainage requirements of the materials.

The reduction in the permeability of the crushed limestone with the addition of 5% shingles was an interesting finding. By examining the gradation of the crushed limestone (Figure 1 and Table 1), it can be seen that this material contained a relatively low amount of sand especially particles finer than 2.36 mm as shown in Figure 1. The high permeability of the crushed limestone is a result of the relatively open gradation of this material. It was thought that the addition of 5% ground shingles, which has a maximum size of 4.75 mm (Figure 2), resulted in modifying the gradation of the limestone and made it similar to that of RCA 2. This reduced the permeability of the limestone to a value within the range obtained for RCA 2, as shown in Figure 9. To examine this hypothesis, the permeability of crushed limestone mixed with 5% sand (passing 4.75 mm-sieve) was tested and found to be very close to that of the crushed limestone with 5% shingles, as shown in Figure 9. Hence the reduction in the permeability of limestone with 5% shingles was a result of increasing sand-size fraction in the material rather than due to some specific property of the ground shingles.

GENERAL DISCUSSION ON STABILITY RESULTS

Looking at the three RCAs, the effect of shingles on the stability of the three materials could be related to the fine contents of the material. The higher the fines content, the more noticeable the positive effects of shingles on enhancing the stability. Indeed, RCA 1 which has the highest amount of fines showed the greatest enhancement in stabilization with the use of shingles. On the contrary, RCA 3 showed reduced stability with the use of shingles as it has the least amount of fines; or put another way, there were insufficient fines to be enhanced by the shingles. There is also a possibility that the stability of this material (RCA 3) stems from interlocking of the coarse particles with optimum amount of fines to fill the voids between the large particles. Adding the shingles could have reduced such interlocking and resulted in less stability.

Coarse particles are unlikely to be affected by shingles since the size of the ground shingle is much smaller than the coarse aggregate particles. Also, angular particles (both coarse and fine) exhibit excellent interlocking properties which provide high stability. Using shingles with angular particles may reduce the interlocking and shear strength of the materials and, hence reduce the stability.

While the effect of shingles on the stability of the three tested RCAs could be attributable to the amount of fines, the role of shingles in the case of natural granular materials could be attributable to the quality or, more specifically, the angularity of the fines. In the case of limestone, the fines are angular and strong. The high stability of this limestone materials stems from the interlocking of these and the large coarse particles. Adding shingles, hence, would not have any beneficial effects; on the contrary, the shingles appear to reduce the interlocking and shear strength. The crushed natural gravel showed a different trend since the fines were not as angular at those in the limestone; this is why there was some improvement in stability when shingle was added.

CONCLUDING REMARKS

The results presented in this paper confirmed the feasibility of using tear-off shingles to enhance the performance of granular materials used as road base/subbase or as surface course for unpaved roads. Within the range of materials investigated in this study, the following specific conclusions are drawn: (1) the addition of 5%, and in some case up to 8%, tear-off shingles was found to enhance the stability of the granular materials, (2) in cases of granular materials with high CBR (above 100%), the addition of shingles was found to have no positive effects, and in some cases negative effects, on the stability as determined by CBR, and (3) the drainage characteristics of the tested granular materials were not significantly affected by the addition of shingles.

Although the CBR results showed that some granular materials would not benefit from the addition of shingles, it should be noted that the reduction in CBR for such material was not significant and did not render the material unsuitable for road works. Indeed the minimum CBR obtained for the 5 tested granular materials at 5% shingle was 80% (Figures 4 and 5). Note also that more testing, including in-situ tests, are needed to provide a comprehensive evaluation of the effects of shingles on granular materials. This is currently under investigation by the authors.

In addition to stability improvements, it should be emphasized that the use of shingles could have other environmental and economic beneficial effects on granular materials. These include reducing the amount of materials disposed in landfills; and hence, promoting construction sustainability. Moreover, the binding effects of the shingle could have positive effects on reducing the dust generation during construction or during the service life of unpaved gravel roads. The effects of addition of shingles on dust generation will be investigated by the research team. An earlier research work by the authors (unpublished) has also shown that the addition of ground shingles to fine-grained soil reduce the water capillary rise. This constitutes additional benefits of using shingles especially in situations where frost damage is a concern.

ACKNOWLEDGEMENTS

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Table 1: Micro-Deval values, and fractions of sand and fines of the granular materials used in this study

Material	Micro-Deval Loss (%)	Sand (%)	% fines (Passing 75um)
RCA 1	20.3	44.64	7.85
RCA 2	17.9	49.07	5.12
RCA 3	18.5	45.23	2.62
Crushed limestone	7.3	37.94	8.58
Crushed Natural Gravel	5.4	55.50	7.50

Table 2: Optimum moisture content (%) and maximum dry density (kg/m^3)

Shingle content %	RCA 1		RCA 2		RCA 3		Crushed limestone		Crushed Natural Gravel	
	OMC	Density	OMC	Density	OMC	Density	OMC	Density	OMC	Density
0	9.0	2054	8.9	2106	8.7	2106	5.9	2260	5.1	2293
3	9.2	2025			8.6	2038	6.0	2262		
5			8.5	2071	8.9	2027	6.2	2229	5.2	2198
8	9.1	1967			8.7	2003	6.4	2187		
10	9.3	1964	8.3	1992	8.4	1997	5.9	2176	5.2	2182
15	8.6	1953					5.8	2144		

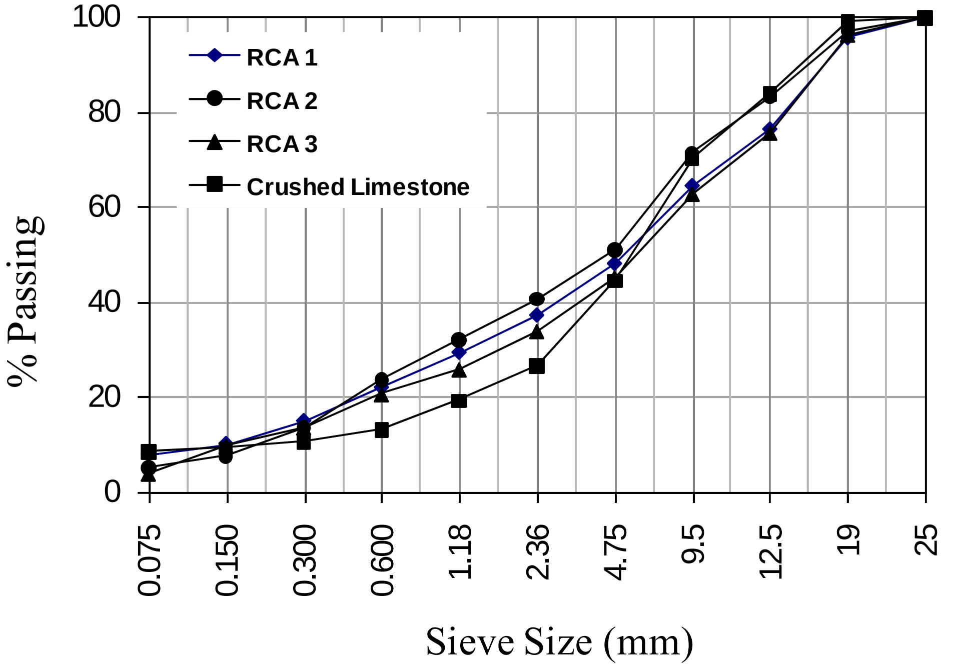

Figure 1: Grain size distribution of the crushed limestone and three RCAs

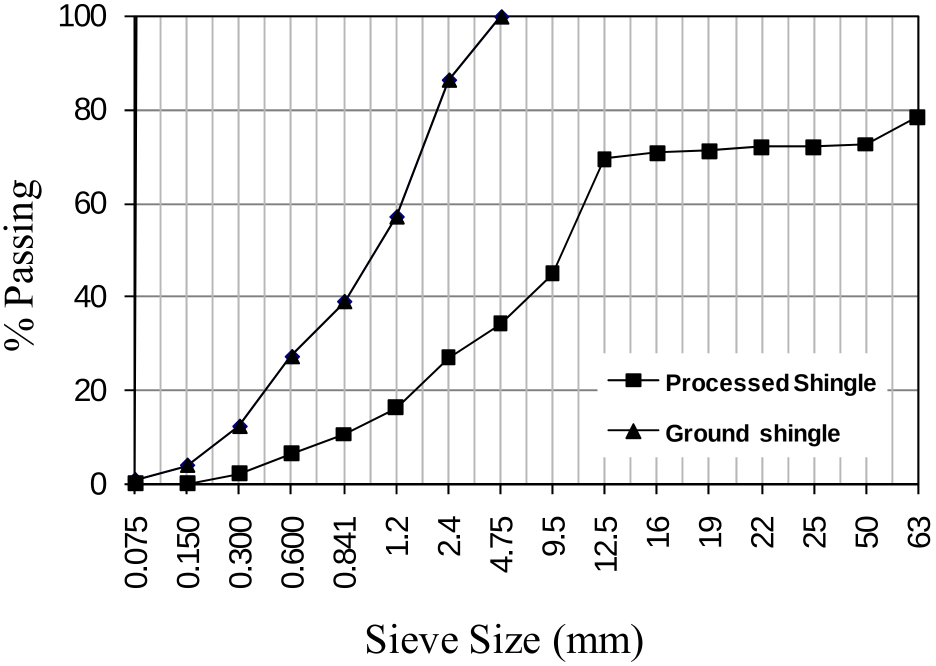

Figure 2: Grain size distribution of processed and ground shingles

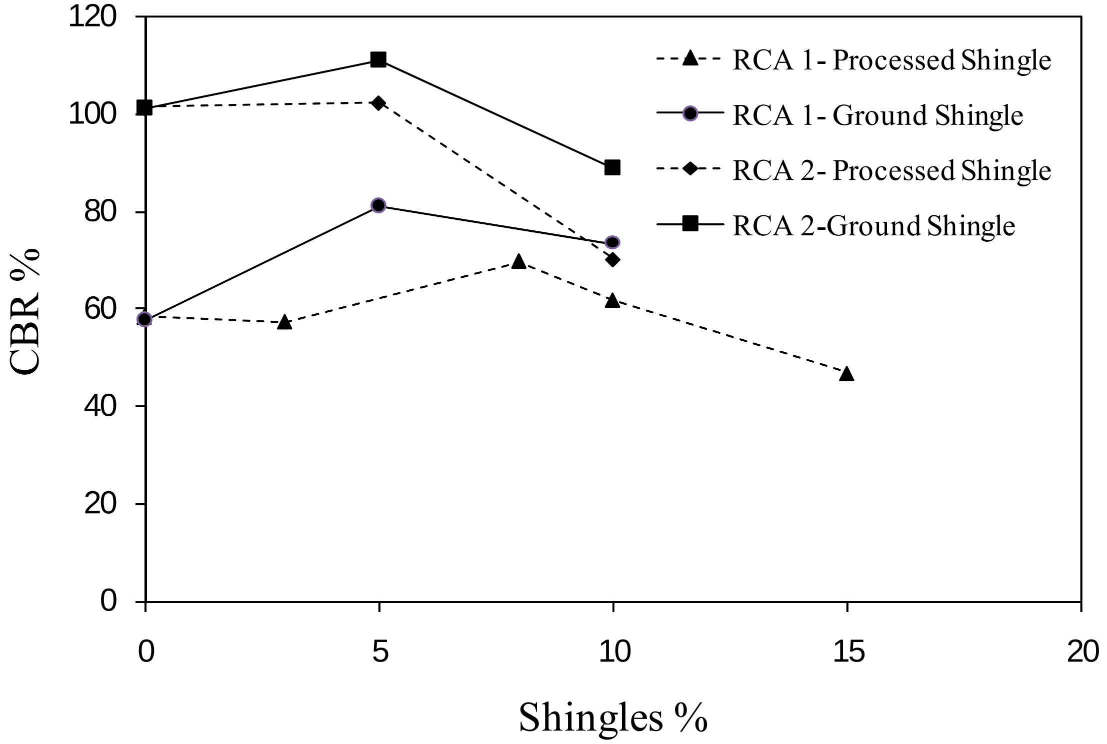

Figure 3: Effect of shingle content and size on stability of RCA

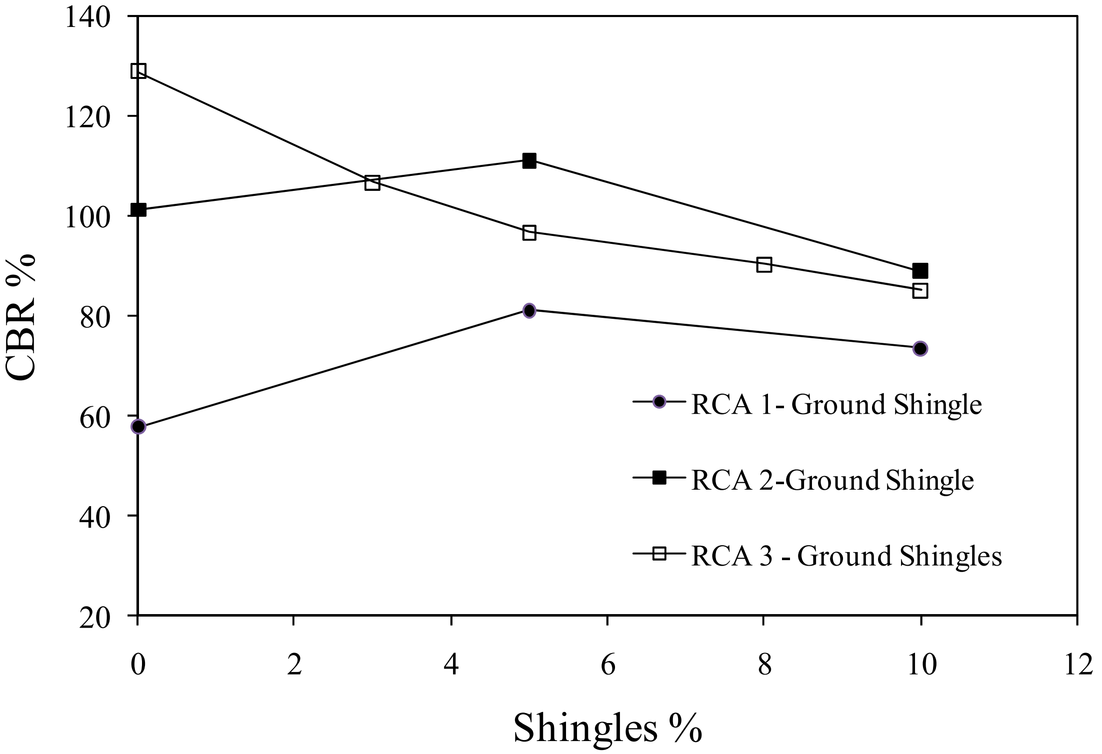

Figure 4: Effect of shingle contents on stability of RCAs

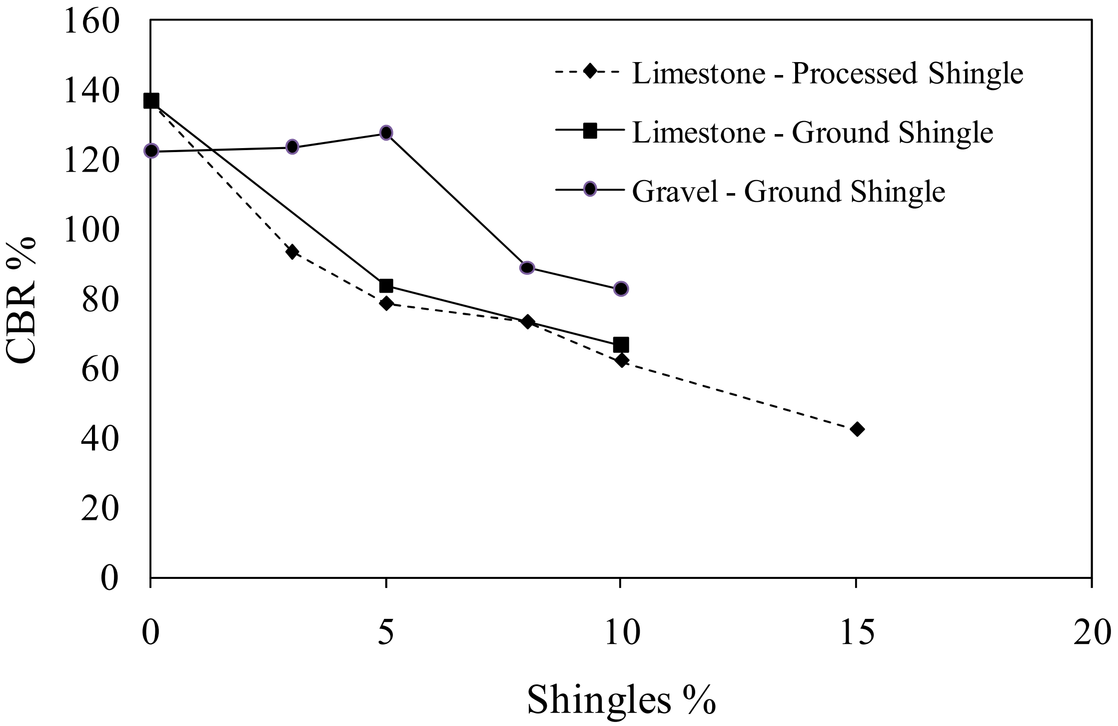

Figure 5: Effect of shingle content on stability of natural granular materials

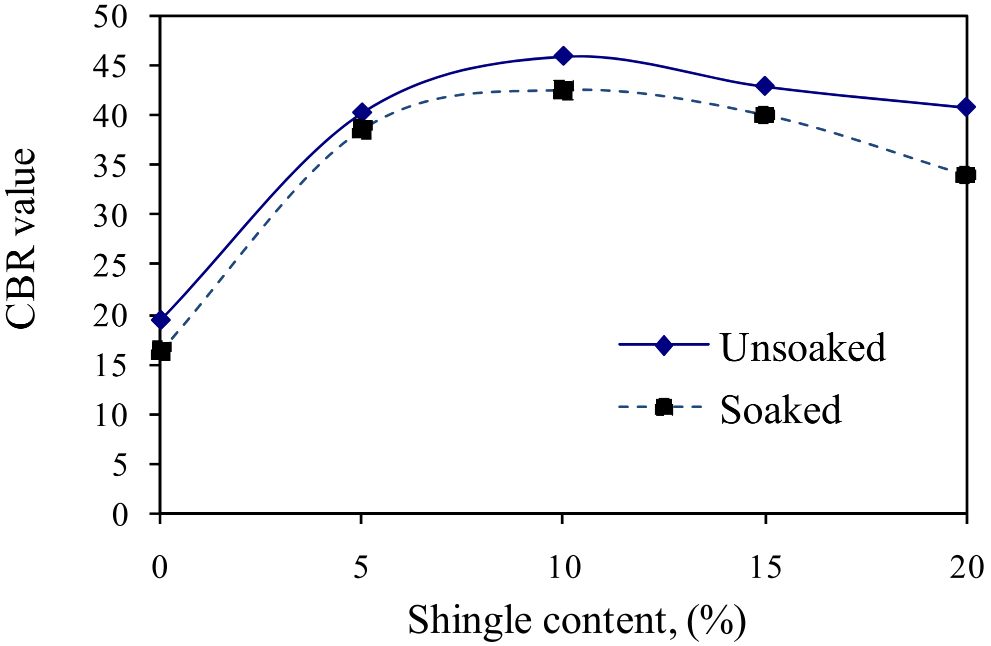

Figure 6: Effect of shingle content on the stability of fine-grained soil

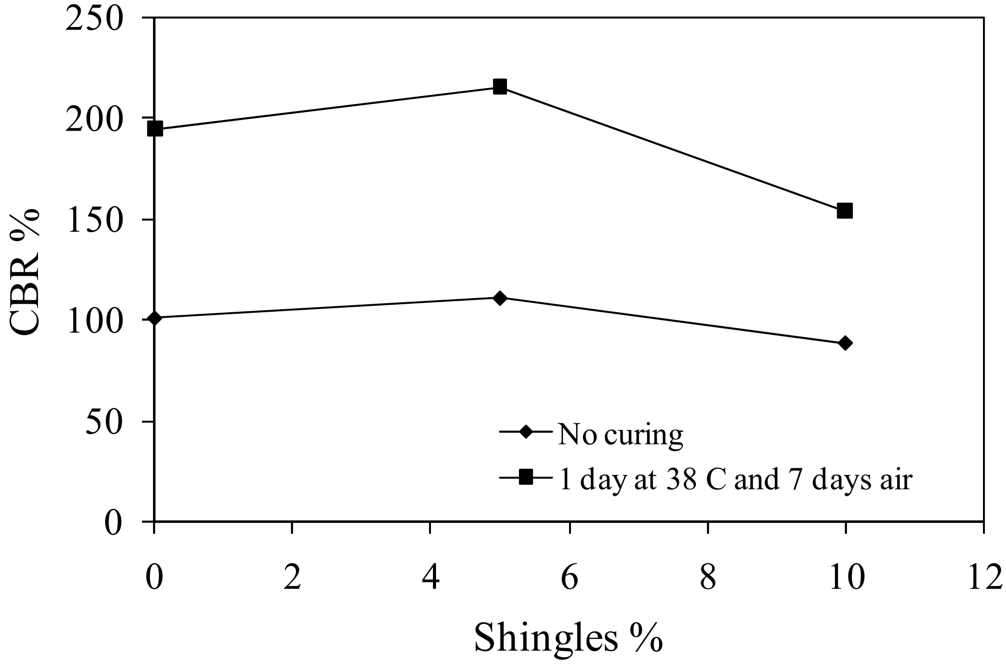

Figure 7: Effect of heat and air curing on stability of RCA 2 containing ground shingles

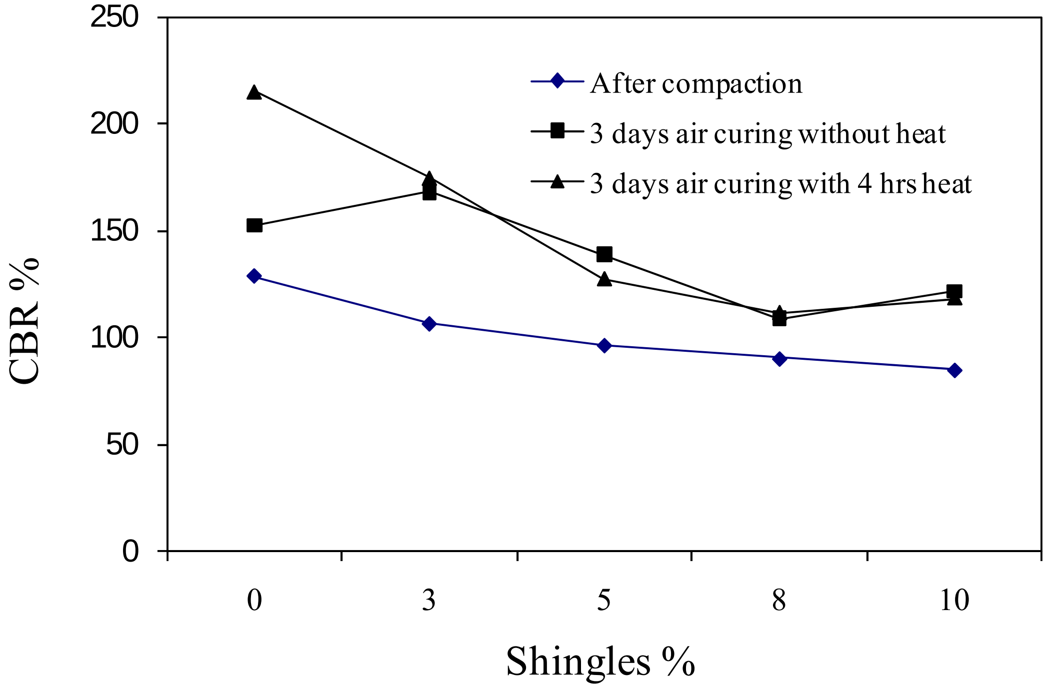

Figure 8: Effect of heat and air curing on stability of RCA 3 containing ground shingles

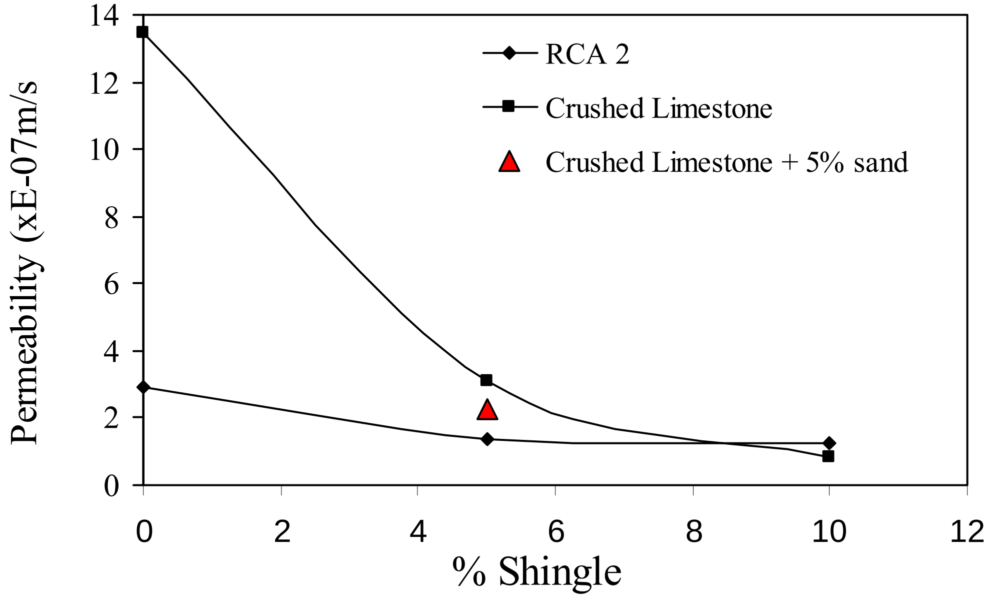

Figure 9: Effect of shingles on the permeability of RCA 2 and crushed limestone