Waste Aggregate in Concrete Pavement – A Review

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Abstract : This article focuses on review of recent findings on potential of waste aggregate in concretepavements. Waste aggregates namely RCA (Recycled concrete aggregate), RAP (Recycled Asphalt Pavement) and WFS (Waste Foundry Sand) were considered in the review study. There are considerable laboratory findings for use of waste aggregate in concrete pavements. However, there is limited information available on field studies in Indian scenario. From the studies conducted in United States and Europe, it is clear that RCA and RAP do perform when used as aggregate in concrete pavements.There is no specific information available on field performance of WFS in cement concrete, but laboratory studies show that WFS can be partially replaced for fine aggregate in cement concrete pavement.

Keywords: RCA, RAP, WFS, cement, concrete, pavement

I. INTRODUCTION

Industrial waste generation has become a major concern for the nations of the world. With growing population and urbanization of the places, waste generation is expected to grow tremendously. Effective waste management requires a good coordination between industrial professionals, businesses leaders and government organization. Often, cost considerations and management skills dictate whether waste reduction can be accomplished. When it comes to handling and utilization of waste, highway construction has become a favorable arena for its effective disposal. The highway structure is composed of materials of varied properties, and requires careful attention towards selection based on experience and specified guidelines.However, the use of recycled material in highway application still remains limited, due to posed regulations, environmental concerns, and technical restrictions. This article focuses on recent findings related to the potentials of recycled concrete aggregate, recycled asphalt pavement, and waste foundry sand in concrete pavements. It reviews the results from recently published articles which are not limited to laboratory findings.

II. RECYCLED CONCRETE AGGREGATE IN RIGID PAVEMENT

The use of RCA in concrete pavement still remains questionable, even after comprehensive laboratory studies. The major challenge encountered in using RCA in concrete pavement is variability of the RCA material. This can result in undesirable alteration to the material properties, often affecting performance of the concrete pavements in service. In United States, many state DOT's (Department of Transportation) have used RCA in concrete pavements with mixed results and performance [1]. RCA has higher water absorption and lower specific gravity compared to the natural aggregates [2]. Laboratory studies indicate that fine RCA show absorption value between 6% and 12%, while coarse RCA shows between 2% and 5% [3, 4]. To compensate the higher absorption of RCA, contractors often end up adding extra water which affects the permeability of concrete; this eventually affects the durability of concrete in field. The use of fly ash in such situations has shown to reduce the permeability of concrete [5]. Pre-wetting the RCA for atleast 48 hours prior to concrete mixing can help in reducing the negative effects of higher absorption of RCA [6]. The use of fine RCA in concrete pavement is not recommended because of its high absorption. However, in Switzerland a concrete pavement section was constructed using 100% RCA, and it showed good performance when compared to the conventional concrete pavement. The success behind good performance was use of different size aggregates, resulting in improved gradation of aggregate in concrete mixture. Also the old aggregates were 100% saturated prior to the mixing [6]. A study performed by Missouri Department of transportation with variable replacement percentage of fine RCA by volume and fixed replacement percentage of coarse RCA, did not affect the 91 day compressive strength significantly [7]. Reduction for 1 day compressive strength for 30% and 40% RCA was 10% and 23%, respectively. Further, this was limited to 7% and 12% at 91 days. Both reference and RCA mixtures exhibited almost similar shrinkage strains [7]. Figure 1 illustrates the shrinkage strain for concrete mixtures containing RCA. At 180 days the maximum drying shrinkage was 600 µ□ [7]. EMV (equivalent mortar volume) mix design which requires the total mortar content in conventional mixtures to be equal to the mortar content of RCA made concrete, showed least shrinkage among all the mixtures.This was due to lower content of fresh mortar and higher content of coarse aggregate [7]. Inclusion of fly ash upto 40% and maintaining low w/cm of 0.37 helped in reducing the shrinkage of mixtures proportioned with 20% fine RCA to 425 µ□ [7]. The field measured shrinkage for concrete pavements with RCA is shown in figure 2 [7]. The coefficient of thermal expansion was slightly affected with RCA. The 60 days and 330 days CTE was observed to be 7.88 µm/m/°C and 7.56 µm/m/°C, 8.24 µm/m/°C and 7.74 µm/m/°C, and 8.68 µm/m/°C and 7.88 µm/m/°C, for reference mix, 30% RCA mix, and 40% RCA mix, respectively. According to the recent study performed [7], the incorporation of RCA do affect the strength, drying shrinkage and coefficient of thermal expansion of concrete, in laboratory as well as field. Butthe overall investigation showed almost similar performance for both conventional and RCA concrete mixtures in service.

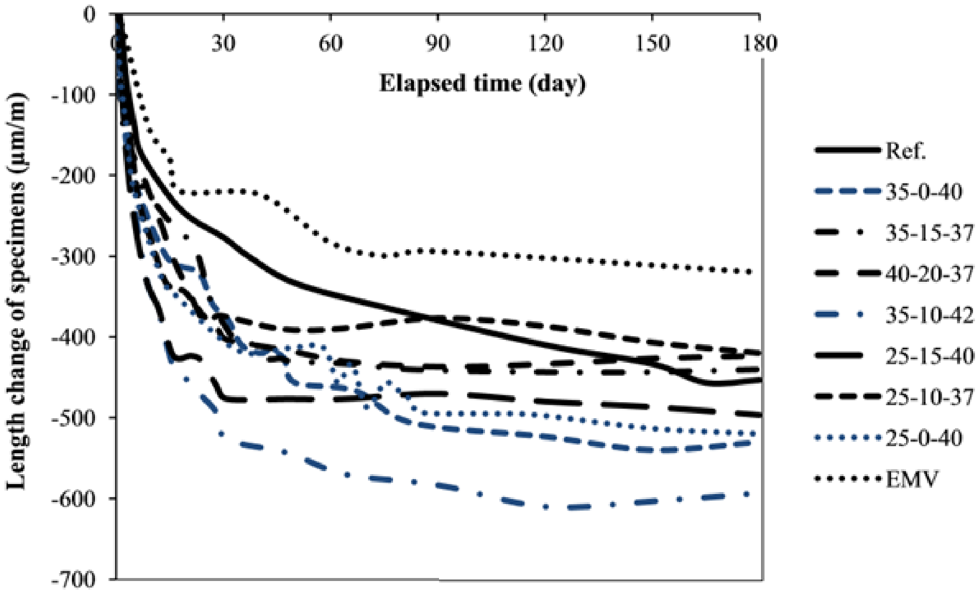

Figure 1. Laboratory shrinkage strain of concrete mixtures investigated [7]

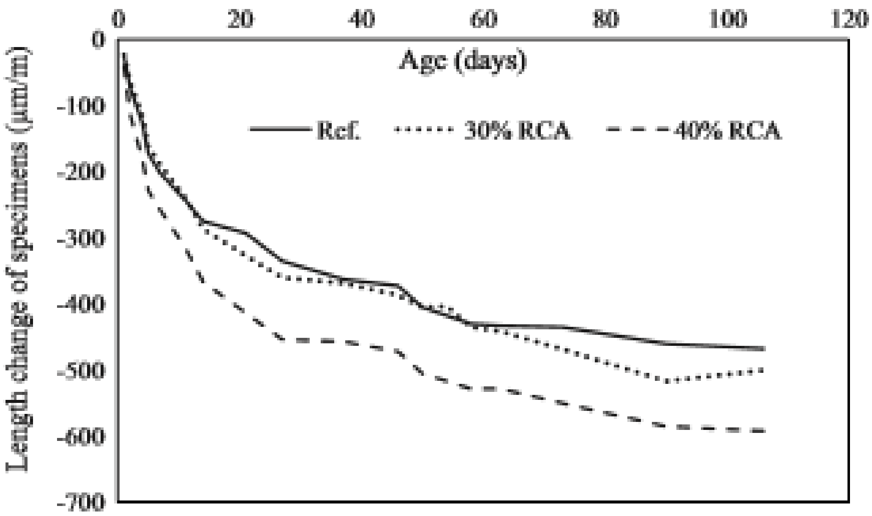

Figure 2. Field shrinkage of concrete containing RCA [7]

III. POTENTIAL OF RECYCLED ASPHALT PAVEMENT IN CONCRETE PAVEMENT

During the rehabilitation of existing asphalt pavement, materials are removed while resurfacing and reconstruction of the road surface. The removed and processed material consists of aged binder and aggregate, which becomes recycled asphalt pavement (RAP). Every year million tons of recycled asphalt pavement is generated all over the world. Part of this material is recycled into the existing asphalt pavement and highway base. However, its full potential still remains underutilized due its limitations and regulations posed by highway agencies. Another great potential for its use can be in concrete pavements. Since concrete pavement construction requires huge quantity of aggregates, the use of RAP as aggregate in concrete pavement can incur huge savings and sustainable practice in construction industry.

The effect of RAP on mechanical properties of cement concrete has been investigated in past [8, 9, 10, 11].Coarse and fine RAP replacement rates of 0, 25, 50, 75, and 100 percent, with different W/C ratios of 0.45 and 0.50, showed that concrete entrapped air increased slightly, decreased the unit weight, and decreased the slump of the concrete. Reduction in modulus of elasticity, and compressive strength was also observed with increase in the percentage of RAP replacement. It was concluded that concrete containing high percentage of RAP should be used for non-paving applications [8]. In case of RAP aggregate in concrete the crack propagates along the aggregate due to thin asphalt film, and thus avoids the propagation of crack through the aggregate as shown in figure 3 [10]. Strength properties of concrete decrease with increase in the percentage of RAP replacement in cement concrete. Both Fine RAP and coarse RAP replacement result in decrease of the strength of concrete. The reduction in flexural strength is 10% to 20% lower than the corresponding reduction of compressive strength [12]. This can benefit concrete pavements in service. Performance properties of concrete containing RAP improves with use of fly ash with respect to porosity and permeability of concrete [13]

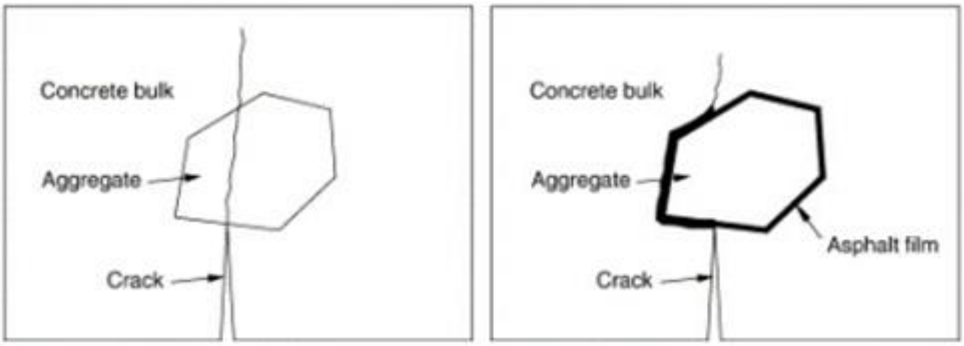

Figure 3. Propagation of crack through aggregate without and with asphalt film [10]

In Austria a concrete pavement was constructed using recycled concrete aggregate from existing concrete pavement and RAP from preexisting asphalt overlay. The overall performance of concrete pavement with recycled aggregate was found to be good with no reported problems associated to premature failure [14].In a study conducted by University of Florida the potential of RAP in cement concrete for rigid pavements was evaluated. According to the study, RAP in cement concrete reduces the elastic modulus of concrete and therefore reduce the induced stresses at the applied loads [15, 16, 17, 18]. There was also effect of temperature on tensile strength of concrete mixtures containing RAP. For instance, the tensile strength of concrete containing RAP at early age was seen to increase as the temperature decreased. However, this was not seen for concrete at later ages [19, 20, 21]. Incorporation of RAP in concrete reduces the concrete strength, but it also reduces the elastic modulus of cement concrete [22, 23, 24]. This can benefit concrete pavements in service, since the induced stresses are much lower for the concrete mixtures with lower elastic modulus, when compared to concrete mixtures with higher elastic modulus. At 90 days, drying shrinkage increased as the percentage of RAP replacement increased, as shown in figure 4. At 91 days, the coefficient of thermal expansion was 7.38 µm/m/°C, 8.01 µm/m/°C, 8.46 µm/m/°C, 9.36 µm/m/°C, and 10.53µm/m/°C for concrete mixtures containing 0%, 20%, 40%, 70%, and 100% RAP replacement, respectively. The coefficient of thermal expansion for concrete containing RAP is shown in figure 5.

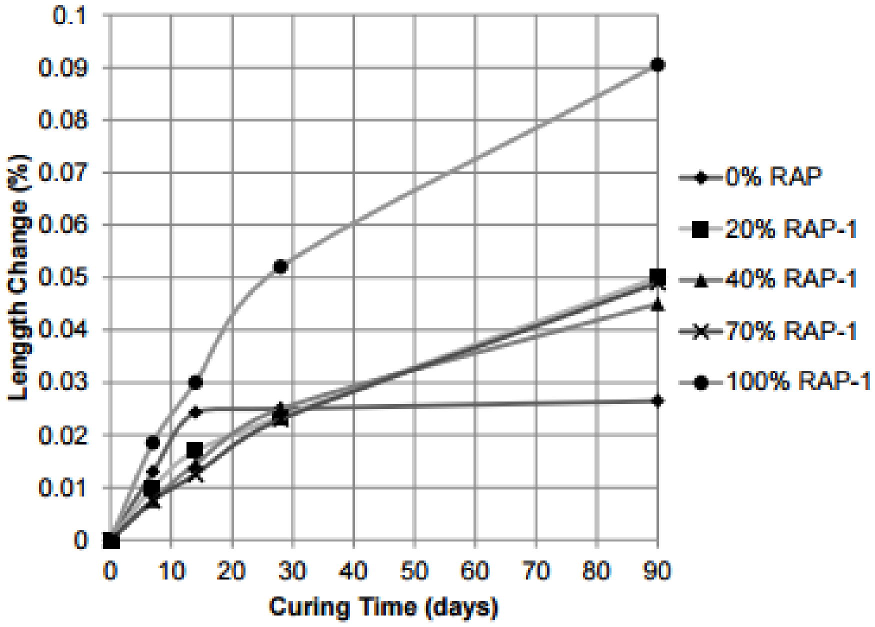

Figure 4. Length Change for concrete mixtures containing RAP [12]

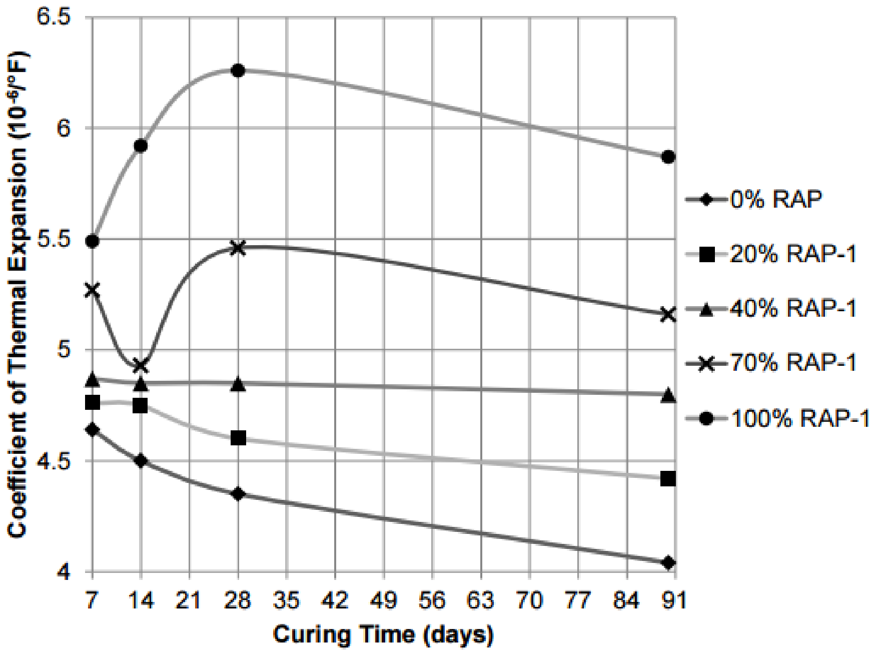

Figure 5. Coefficient of thermal expansion of concrete containing RAP [12]

IV. POSSIBILITY FOR REUSE OF WASTE FOUNDRY SAND IN CONCRETE PAVEMENT

Foundry sand is the waste generated from metal casting industry. Metal casting industries use high quality silica sand with binders to create casting moulds. Studies show that waste foundry sand can be partly replaced for natural fine aggregate. The limited percent replacement (upto 10%) should provide performance equivalent to that of conventional mix [24]. However, higher replacement of WFS affects the workability and mechanical properties of concrete negatively [25]. Interestingly, the effect of WFS on flexural strength of concrete seems to be marginal. For instance, figure 7 shows the percentage decrease in concrete strength for mixtures containing WFS replaced for slag sand in increments of 15%, 30%, and 45%, respectively. Among all the strength properties, flexural strength was least affected by incorporation of WFS in cement concrete [25]. This behavior can benefit concrete pavements in service. There are no specific studies which evaluate the performance of WFS in concrete pavement. Laboratory studies show that limited percentage of WFS can be used in concrete pavements, but it needs field evaluation to validate the performance and potential of the material in pavement application.

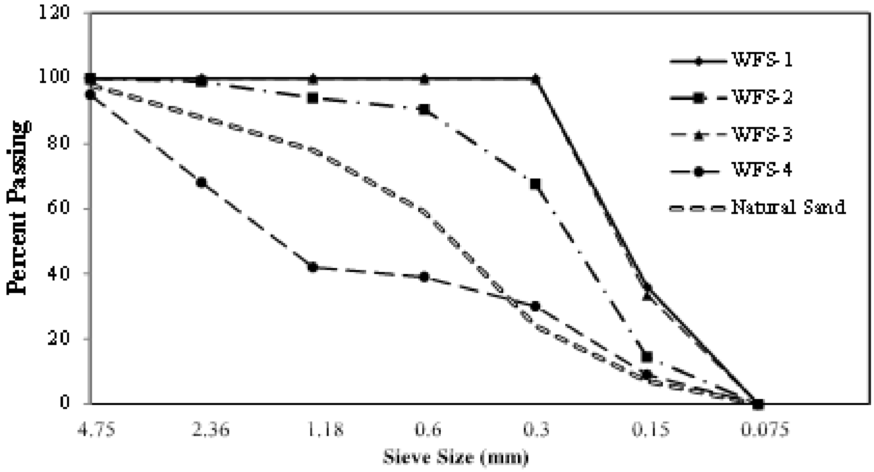

Figure 6.. Particle size distribution of WFS [24]

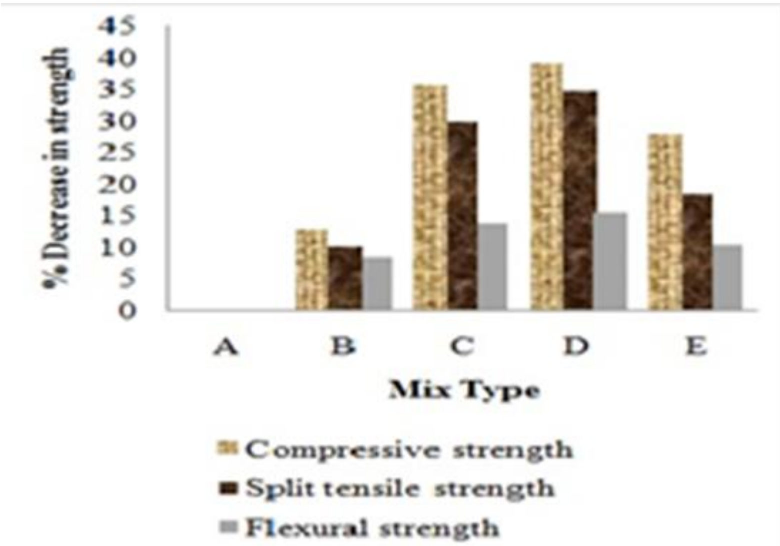

Figure 7. Decrease in strength properties of concrete containing WFS [25]

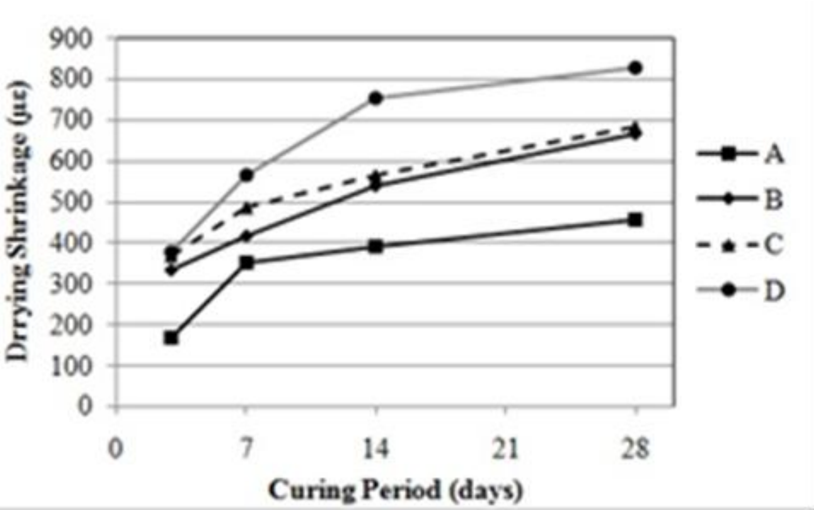

Figure 8. Shrinkage strain of concrete containing WFS [25]

V. CONCLUSION

This article focuses on review of recent findings on potential of waste aggregate in concrete pavements. It specifically focuses on three waste materials namely RCA (Recycled concrete aggregate), RAP (Recycled Asphalt Pavement) and WFS (Waste Foundry Sand). Comprehensive information is available on laboratory findings for use of waste materials in cement concrete pavements. However, there is limited information on field performance of waste materials in concrete pavements, especially in developing country like India. Both RCA and RAP have shown to perform well in service when used in concrete pavements. Typically, it is favorable to use 30% to 40% coarse RCA replaced for virgin coarse aggregate in concrete pavements. Similarly, upto 40% coarse RAP has shown to perform when used in concrete pavements in United States and Europe. The addition of RCA and RAP affects the strength properties, drying shrinkage and coefficient of thermal expansion of concrete. But the field performance of this material shows to be almost similar to the conventional concrete mixtures. When using waste aggregate in cement concrete, addition of fly ash shows to improve the durability of concrete mixtures. Laboratory studies show that addition of WFS in cement concrete affects the strength properties of concrete, andlimited replacement of fine aggregate with WFS [upto 20%] has the potential for application in concrete pavements. There are no specific studies which evaluate the coefficient of thermal expansion of concrete mixtures containing WFS, and therefore it is very difficult to predict the potential performance of WFS in concrete pavements. However, strength properties of concrete containing WFS do show the potential for the material in concrete pavements.

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