# Roller Compacted Concrete for Rigid Pavements- A review

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***Abstract* - Roller compacted concrete (RCC) is durable, economic and environment friendly material commonly used for construction of heavy industrial floors and roads (low speed and arterial). The production RCC in a large quantity leads to emission of excessive CO2 and there by damages the environment. Hence, it is essential to identify the eco-friendly binder materials for partially replacing the cement. This paper summarises present trends and past findings of use of various sustainable materials for production of roller compacted concrete (RCC) for construction of rigid pavements. Natural aggregates replaced with different % of Reclaimed asphalt pavement (RAP) material and red mud is replaced with different % of as a cementitious material in the RCC may reduce the excessive quarrying of raw material and usage of cement. Also, RCC has many advantages, and the main attraction is its low water requirement with high workability and high compaction. This automatically results in more compressive strength. In this paper, the review of the papers has been presented in order to come to an overall understanding of the past findings and current trends and future scope of the RCC for pavement applications.**

***Index Terms* - RAP, Red mud, GGBS, mix design, RCC**

## 1.INTRODUCTION

Concrete is one of the innovative materials in construction industry. Usage of Concrete in pavements applications have gained researchers interest in 19th century owing to its high strength and durability under harsh environment. It has been used in various applications viz., highways, airports, streets, local roads, parking lots, industrial facilities, and other types of infrastructure. Rigid pavement constructed with concrete offers great service with less maintenance. However, in recent years the emission of $CO_2$ from cement industries dramatically increased due high demand to satisfy the human needs. Hence, partial replacement of cementitious material and recycled aggregates reduces the quarrying excessive amount of raw materials and there by prevents the emission of large amount of $CO_2$. Following sustainable practice brings greater focus on long-term affordability, quality, and efficiency (Nagalakshmi, 2013).

Sustainable concrete requires low energy demand, can be manufactured with recycled material, utilises widely available resources in environment, offers long lasting infrastructure (Naik, 2008). In recent studies, it was highlighted by several researchers that, Cement industry is one of the major contributors in emission of carbon dioxide. Babor et al. (2009) reported that, $CO_2$ emission from the production of concrete is directly proportional to the percentage of cement content used in the concrete mix. For example, 900 kg of $CO_2$ are emitted for the fabrication of every ton of cement, accounting for 88% of the emissions associated with the average concrete mix. Later, Shafigh et al., 2014 also concluded that, it is essential to identify the substitution for cement owing to yearly production exceeding 10 billion tons of concrete across the world.

Now a days usage of Roller-compacted concrete (RCC) gained researchers attention due to high strength and stiffness. RCC made with special mix proportion to achieve zero slump, and widely popular due to its economic and fast-to-construct features (Debbarma et al., 2019). It is stiff mixture of three key construction materials namely aggregate (fine and course), binding material (cement, fly ash, Ground granulated blast furnace slag etc.), and water. In field, RCC is well compacted by vibratory rollers to achieve high stiffness matrix with grater stiffness and strength parameters. It is well known fact that, the concrete hardened with time and gains strength due to pozzolanic reactions. Unlike conventional concrete, RCC has different mixture proportions to achieve higher strength. This can be achieved with well-graded aggregates, adequate amount of cement and its grade, water content, and dense compaction. Also, researchers in past one decade reported that, sometimes RCC pavements can achieve higher strength and stiffness than conventional concrete, with low permeability by adopting proper mix design. Its consistency is stiff enough to remain stable under vibratory rollers yet wet enough to permit adequate mixing and distribution of paste without segregation.

## 2.VARIOUS SUSTAINABLE MATERIALS AND THEIR USE

Fly ash, GGBS are two most commonly used pozzolanic material for partial replacement of cement. However, in recent days many authors proposed that, red mud also can be used in for partial replacement of binding material. Red mud, Fly ash, and GGBS are end products of aluminum, power plant and steel industries. Hence, usage of these waste material in partially replacement of binding material in RCC reduces the emission of $CO_2$ from cement industries and thereby global warming. In addition, Reclaimed Asphalt Pavement (RAP) also, attracted many researchers in past one decade to utilise in partial replacement of fresh asphalt concrete and RCC. However, the current study manly focusing on use of sustainable material in RCC, usage of RAP and other binding material in production of RCC for construction of rigid pavement have been explained in following sections.

### 2.1 Fly ash

Fly ash is waste material or residue product obtained after burning the coal at high temperature in coal power plants commonly used to improve some engineering properties (strength and stiffness) of concrete for reducing cost of construction (Bentz & Ferraris, 2010). The researchers (Cao et al., 2000) commented that, the chemical composition consists unfixed $SiO_2$ and $Al_2O_3$ and hence exhibits comparatively high pozzolanic activity. Similarly, it shows Morphologic effect, and micro aggregate effect. The authors also explained that pozzolanic effect plays crucial role in, activation of $SiO_2$ and $Al_2O_3$ by Ca(OH)2 product of cement hydration, there by yield more hydrated gel. The typical specific gravity of FA lies in the range of 1.3 to 4.8 (Joshi & Lohita, 1997) and the particle size is less than 45 microns, which are usually spherical in shape.

Every year millions of tonnes of Fly ash produced around the globe including India (80 million tonnes per year) of the total production. However, out of all, only a smaller amount < 10% is being used in various construction industries. Thus, the majority of the Fly ash dumping in the landfill (Yerramala & Babu, 2011; Siddique, 2003). The report published by Ragan (1988) stated that, most of the RCC mixtures used for rigid pavements in USA either Class C or F. Yerramala and Babu (2011) concluded that, fly ash can be utilised in high volumes up to 50 – 80% by mass of the cementitious material or binder production of RCC for pavement applications. The authors also stated that, the use of fly ash in RCC pavement could be considered as great choice for the infrastructure development to reduce the project cost. Also, it reduces the compact efforts and the heat of cement hydration (Chun et al., 2008).

Atis (2005) has investigated the engineering properties of RCC comprising high volume of fly ash obtained from two different sources and identified as standard type F and other one is non-standard fly ash as per ASTM C618. Two different percentages (50% and 70%) were considered for their investigation as a replacement of binding material. I t was found that, the mechanical or engineering properties of RCC comprising 50% were higher than RCC containing 70% at all curing periods.

Cao et al. (2000) investigated the influence of percentage fly ash replacement instead binder of in RCC on compressive strength at different curing periods. The authors found that, the compressive of RCC having 45% to 95% fly ash contents are exhibits lower strength than control mix at 3 days curing period. Nevertheless, the strength of specimens containing 45% and 55% were satisfactory. From this it can be concluded that, the fly ash effect is negative at 3 days. However, the samples tested at 7 days curing period, showed higher compressive strength than control mix. Hence, it considered that, the strength gaining with curing period significantly depending on percentage of fly ash and curing period. As increasing curing period, the fly ash replaced concrete gains higher strength and after certain curing period even it offers higher strength than control mix. The optimistic effect of fly ash is noticeable after seven days of curing period. Finally, the authors also, found that the samples tested after 90 days curing period, even shows much higher compressible strength than samples prepared with control mix.

2.2 Ground Granulated Blast Furnace Slag (GGBS)
The ground granulated blast furnace slag also popularly known as GGBS is residue obtained from steel industry. It is well known fact that, rising infrastructure demand to satisfy the human needs, necessitates the production of large amount of steel and there by end up with more GGBS. Nevertheless, the recent advancements in concrete, found that GGBS could be used as binder replacement.

Some of investigations done in past two decades by various researchers (Swamy and Bouikni, 1990; Liu et al., 2014; Chidiac and Panesar, 2008) highlighted the influence of GGBS as a partial replacement of binding material (cement) for conventional concrete. The authors concluded that, though the early age strength of concrete is comparatively less with conventional concrete, it substantially improves the compressive strength, stiffness, and durability at later age. Babu and Kumar (2000) investigated the efficiency of GGBS in conventional concrete with cement replacement varying from 10% to 80%. Li and Zhao (2003) reported that the blend of fly ash and GGBS enhances both fresh as well as hardened concrete properties. Similarly, the study carried out by Oner and Akyuz (2007) depicts the optimum usage of GGBS for enhancing compressive strength. The authors found that, the optimum percentage in the range of 55 -59% to achieve maximum strength and beyond this value strength reduction was observed with increasing GGBS content.

In recent a days, various researchers has been reported the potential benefits of GGBS in production of RCC. Rao et al. (2016) examined the strength properties and abrasion resistance of roller compacted concrete made with a binder material (partial replacement of cement with GGBS). The authors stated that the maximum compressive strength found at an optimum value of 40%. Similarly, Arivalagan (2012) investigated use of GGBS in enhancing compressive strength by considering 20, 30 and 40%. The author concluded that, compressive strength increased of all specimens increased after 7 and 28 days of testing, demonstrated that the cement was replaced to a greater extent than 20 percent. Similar response was found in case of split tensile strength as well. The filling action of GGBS is responsible for the increased strength. It was also discovered that the degree of workability of concrete was significantly improved when GGBS was added. With this it can be concluded that, partial replacement of cement with GGBS substantially enhances all engineering properties and improves the workability of concrete in both conventional and roller compacted concrete mixes.

2.3 Reclaimed Asphalt Pavement (RAP)
Over the past three decades, overuse of fresh and natural aggregates in construction of various infrastructure projects, creates its shortage (Singh et al. 2018). In recent days, the use RAP as a substitute to natural aggregates has considerably increased. It is a waste material acquired by removing current flexible pavements for numerous restoration activities (Kumari et al., 2018). Similar to fly ash and GGBS, the generation huge quantity of RAP definitely causes impact to landfills. Hence, it is crucial to utilise these waste materials to achieve sustainable solutions in construction sector. Since RCC is an economic and eco-friendly paving mixture, that can be utilise the RAP could be a great solution for construction of rigid pavements there by reducing the RAP stockpiles. Though utilising the RAP in RCC pavement may possibly decreases its strength, it is beneficial in terms of the initial load-carrying capacity.

The studies conducted by Debbarma et al., (2019), Modarres and Hosseini (2014) revealed that, the optimum moisture content (OMC) of a typical roller compacted concrete mixture prepared using naturally available or fresh aggregates typically lies in the range of 4 and 7%. On the other hand, in case of RAP utilised for partial replacement of natural aggregates, the OMC generally decreases due to the hydrophobic nature of bitumen or asphalt.

Similarly, Debbarma et al. (2019) studied the influence of partial replacement of RAP on compressive strength of RCC. It was found that, the compressive strength decreased by 26 to 67% while less-aged RAP was used in RCC mix. While this percentage reduction of about 9 – 37 % was noticed upon utilization of highly-aged RAP. This behaviour is due to the oxidization effect of the highly-aged RAP aggregates. The researchers include Debbarma et al. (2019), Fakhri and Amoosoltani, (2017) commented that, when the percentage of aggregates replaced with RAP is lesser, the reduction in compressive strength also insignificant. For achieving better pavement performance and strength and stiffness, it is always recombined that, the percentage of RAP for replacing natural aggregated for the production of RCC should be less than 50%.

Flexural strength of pavement is another important parameter to verify or quantify the degree of improvement. Because pavements are subjected to repeated traffic loads induces the tensile stresses at bottom surface of concrete pavement especially when the ground is uneven. Hence, it is essential to investigate the influence of type and age of RAP used RCC mix on the flexural strength. Modarres and Hosseini (2014) reported the use of coarser fraction of RAP gives greater flexural strength compared to the fine fractions. This behaviour is mainly attributed to the lesser asphalt content on aggregate surface area and higher specific gravity as compared to the fine RAP. It is well known fact that, in fine matrix, have more surface area than course matrix. Hence, in case of fine RAP, the asphalt concentration is high, and easily passes the crack through the asphalt layer there by reduces the flexural strength of RCC. Brand and Roesler (2017b) confirmed that RAP concrete mixes fail more in asphalt-cohesion than in the asphalt-cement adhesion. However, the severity of the asphalt cohesion failure might be controlled by using the coarser RAP which contains lesser asphalt concentration and agglomerated particles as witnessed in the recent study reported by Debbarma et al. (2019a). With this, it can be concluded that, use of RAP in RCC mixes is sustainable solution, but it is important to choose coarser and more aged RAP gives better pavement performance over less aged and fine RAP.

## 3.CONCLUSION

The current study summarized the potential benefits of sustainable material namely, fly ash, GGBs and RAP in enhancing mechanical properties of conventional and roller compacted concrete. The use of these sustainable material in RCC greatly reduce the amount of waste deposited in lad fills. The conclusions drawn from extensive critical literature these four sustainable materials are listed as follows.

- The use of mineral admitters like fly ash, GGBS, red mud for partial replacement of cement enhances the mechanical strength of RCC. Also, use of RAP by partially replacing natural or new aggregated shows beneficial outcomes in performance of conventional and RCC of rigid pavement construction
- The optimum percentage Fly ash can be considered as 40-50% for achieving greater performance compared to convention concrete mix. However, the performance better after 90 days curing period.
- Partial replacement of cement with GGBS substantially enhances all engineering properties and improves the workability of concrete in both conventional and roller compacted concrete mixes. The optimum percentage was reported as 40%.
- Use of long aged and coarser RAP perform better than less aged and finer RAP. The percentage RAP for replacing natural aggregated should be restricted up to 50%, beyond this significant strength reduction in RCC causes early failure of pavement.

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