Utilization of Recycled Concrete Aggregate in Bituminous Mixtures

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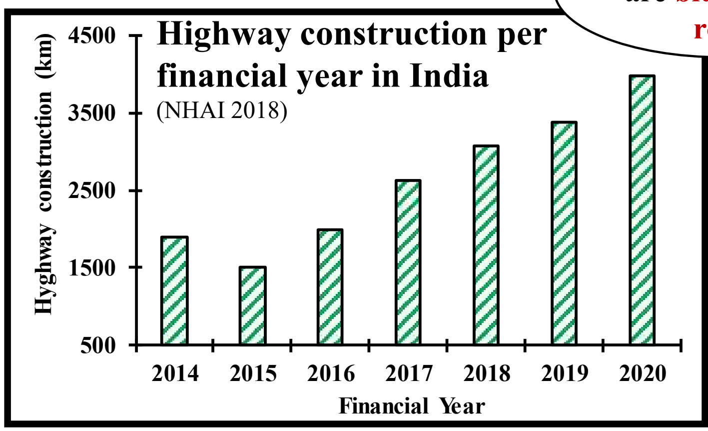
INDIA CHAPTER

INTRODUCTION

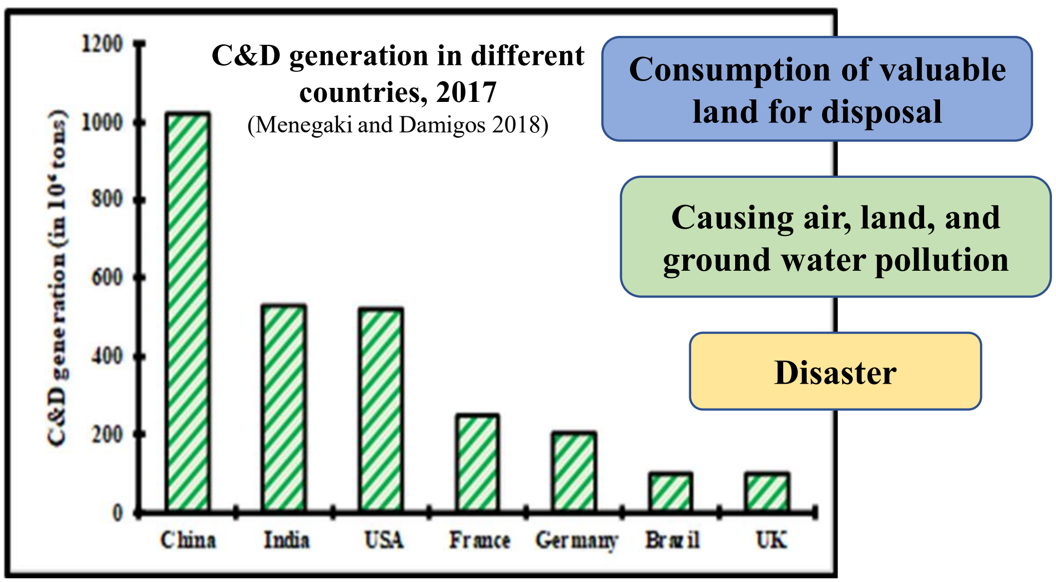
- **Road construction:** **An economic development as well as social benefits**
- **Road in India:**
- **2nd largest road network world wide (MoRT&H)**
- **About 6.22 million km in length in 2016 (MoRT&H)**



C&D waste

- A waste materials produced during the construction, renovation, rebuilding, modification, expansion, repairing, and demolition of buildings and other infrastructure

- Contains aggregates, concrete, bricks, wood, glass, plastic, broken asphalt, metals, etc.,

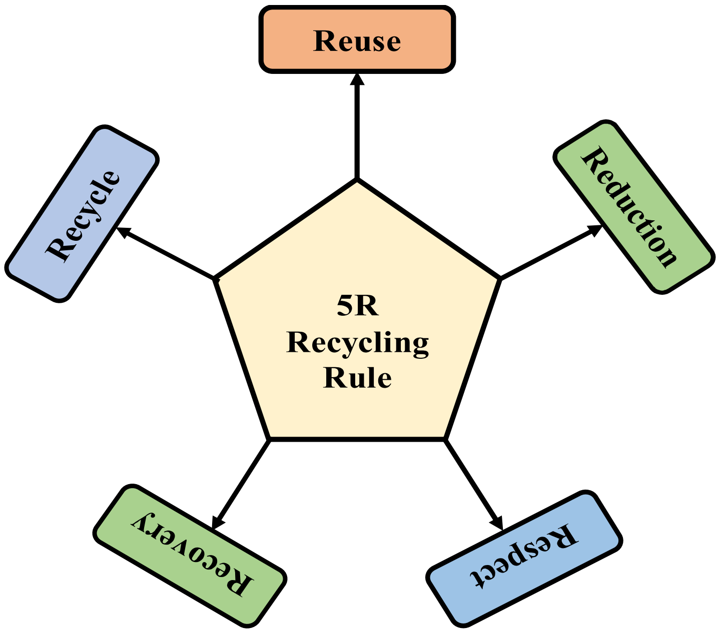


- In India, C&D waste was considered the primary reason for choking up Chennai's sewer system which resulted in the Chennai flood of 2015 killing 500 people and displacing more than 1.8 million people (Ram et al. 2020).

- An illegal construction landfill collapsed in Shenzhen, China in 2015, claiming 75 lives.

Recycling of C&D waste

- **Recycled C&D waste can be used in many fields i.e.**
  - **Geotechnical Application** (Vieira and Pereira 2015)**,**
  - **Geopolymer Synthesis** (Komnitsas et al. 2015; Vásquez et al. 2016)**,**
  - **Sea-wall Foundation** (Yeung et al. 2006)**,**
  - **Landfill Cover Layer** (Rahardjo et al. 2016)**,**
  - **Alternative Pipe Backfilling Materials** (Rahman et al. 2014)**, etc.**



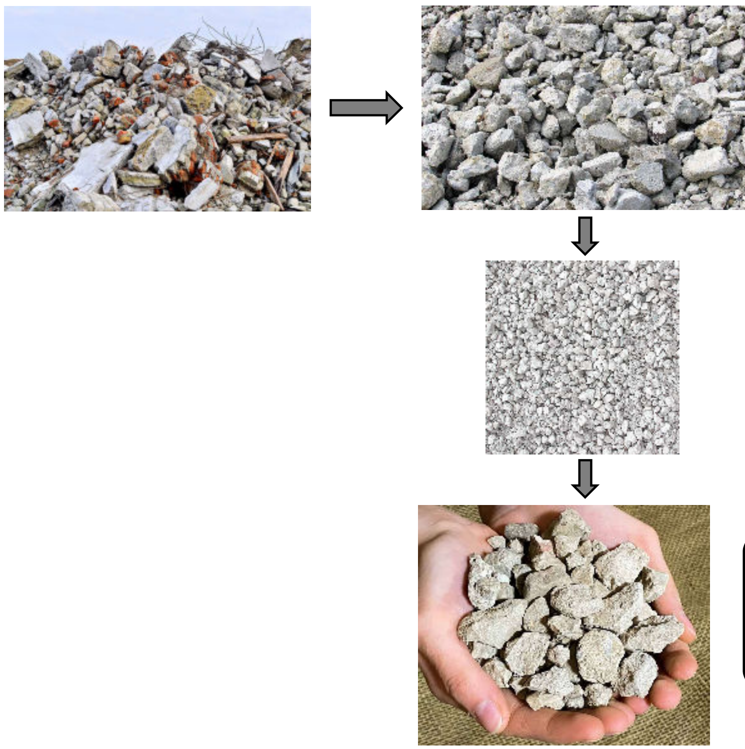
Recycled Concrete Aggregates (RCA)

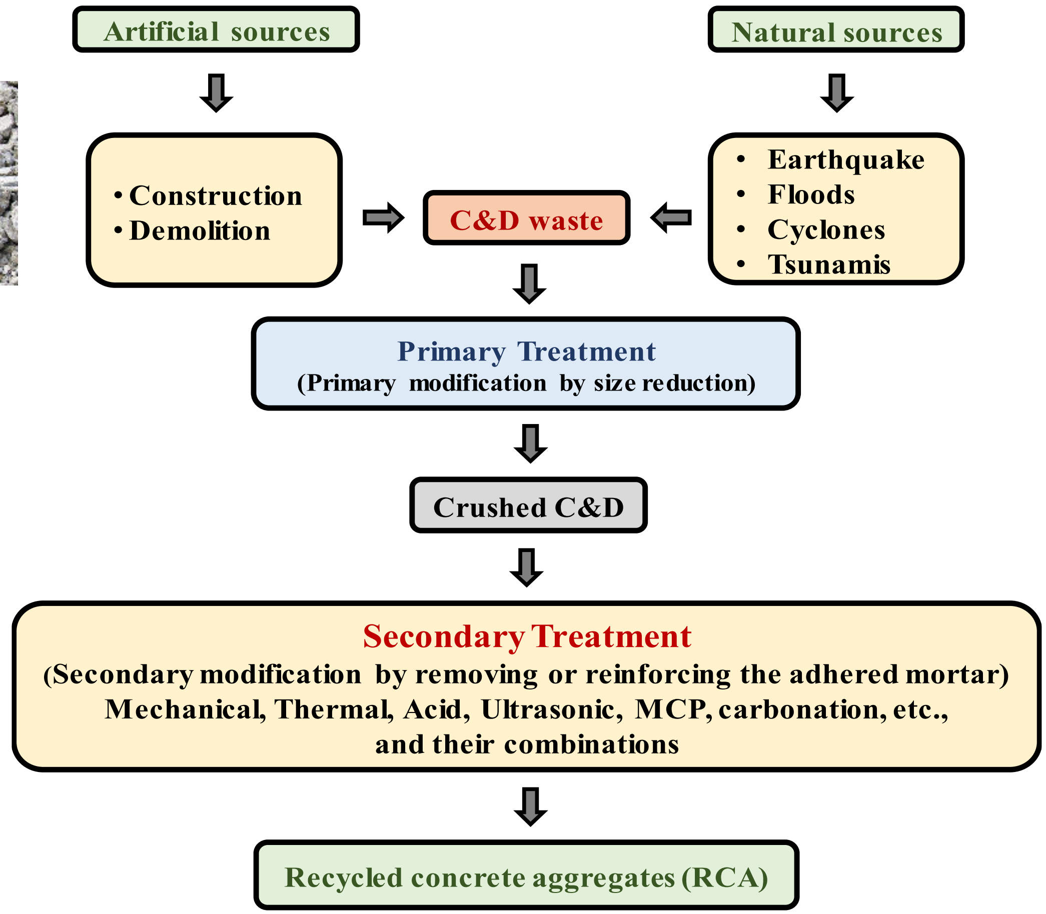
- Produced by recycling the *concrete portion* of C&D waste
- Consist of original natural aggregates and attached /adhered mortars
- Used in unbound pavement, concrete, and bituminous pavement

- Advantages
  - *Preservation of natural resources*
  - *Lower energy consumption*
  - *Lowering harmful gas emission*
  - *Cost benefits*
- Disadvantages
  - *Inferior performance due to high absorption and low density*
  - *Reduce workability*

Components of RCA (Singh et al., 2021)

Production of RCA





Treatment used for Preparation of RCA

Removing the adhered mortars

Thermal

Removing the adhered mortar by creating thermal stress between original aggregate and adhered mortar

Mechanical

Ultrasonic

In a repetitive process, the crushed C&D waste is immersed in water, and an ultrasonic wave is applied

Acid soaking

The interaction of acidic solution and hydration products with adhered mortar results in its weakening and removal

Treatment used for Preparation of RCA

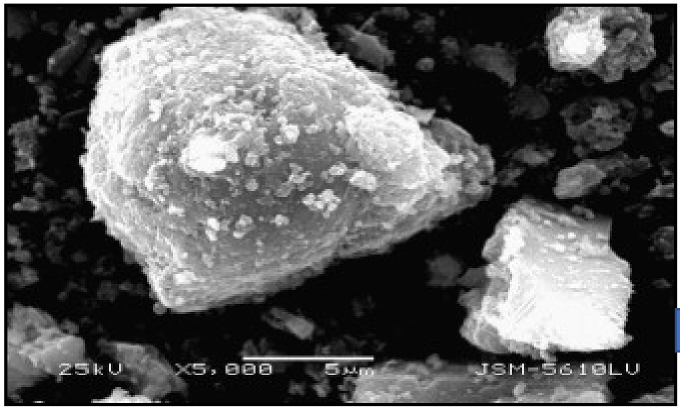
Reinforcing the existing adhered mortars

Carbonation treatment.	Formation of $CaCO_3$ on reaction of CO_2 with adhered mortar, which densify & reinforce
Use of cementitious or pozzolanic materiel	CSH gel formation by the interaction of pozzolanic materials and $Ca(OH)_2$ left in the adhering mortar.
Coating with bitumen emulsion	Obstructing the pores of RCA by employing bitumen emulsion
Incorporation of liquid silicon resin.	The better penetrability, hydrophobicity, and adhesion properties of liquid silicon resin result in reinforcing RCA surface by sealing the pores of adhered mortar and make it activated to the asphalt binder
Microbial calcite precipitation (MCP)	Employing bacteria to produce calcium carbonate crystal precipitation

Characterization of RCA

- **Physical Characterization**
  - ✓ Highly absorptive
  - ✓ Lower density
  - ✓ Higher impact value
  - ✓ Higher abrasion value
  - ✓ Higher crushing value
  - ✓ rough, porous, flat, and irregular in shape

- **Microscopic Characterization**



RCA possess a much rougher surface resulting in higher surface area leading to increase the water and bitumen absorption as compared to virgin aggregate (Chen et al., 2011).

- **Chemical Characterization**

Reference	Chemical composition (%)				
	SiO_2	CaO	Al_2O_3	Fe_2O_3	MgO
Chen et al. (2011)	35.59	29.2	8.04	2.46	1.72
Ma et al. (2019)	49.4	20.65	12.0	-	-
Saberian and Li (2018)	65.21	13.74	4.78	2.33	2.19
Yang and Lim (2018)	54.67	17.38	8.58	5.40	2.18

✓ **Nwakaire et al. (2020) compared the chemical composition of RCA with VA and cement and concluded that the chemical composition of RCA lie between the VA and cement**

Modification in physical properties after treatment

Treatment method	Modification (- and + denotes decrease and increase respectively)			References
	Specific gravity/density	Water absorption	Abrasion value	
Presoaking in HCl and H_2SO4 solution, scrubbing technique and the heating and scrubbing technique	+2.5% (HCL) +8% (H_2SO_4) +4.6% (scrubbing) +13.4% (heat+scrubbing)	-41% (HCL) -48.1%(H_2SO_4) -40.4% (scrubbing) -50% (heat+scrubbing)	-33.3% (HCL) -37.8% (H_2SO_4) -33.3% (scrubbing) -35.6% (heat+scrubbing)	(Purushothaman et al. 2014)
Presoaking in HCl, H_2SO4, and HNO_3 and impingement using silica fumes after HCl soaking	+0.8% (HCL) +7.2% (H_2SO_4) +3.3% (HNO3) +6.1% (HCL & silica fumes)		-19% (HCL) -34% (H_2SO_4) -24% (HNO3) -38.3% (HCL & silica fume)	(Saravanakumar et al. 2016)
Heating (250 and 350°C), soaking ($C_2H_4O_2$ and HCl)	+0.6 to 1.6% (heating) +0.1 ($C_2H_4O_2$) +0.4% (HCL)	-6.3 to 9.4% (heating) -2% ($C_2H_4O_2$) -4.2% (HCL)		(Al-Bayati et al. 2016)
Thermal (20-600 °C) and mechanical (milling time- 5 to 40 min)	+ 3.9 to 7.5 % (thermal) +8.6 to 12.1 % (mechanical)	-24.6 to 66.7 % (thermal) -47.4 to 80.7 % (mechanical)		(Sui and Mueller 2012)
Precoating of RCA using slag cement paste (optimum thickness: .25mm)	-0.9%	+8.9%	-13.72%	(Lee et al. 2012)
Double coating with cement slag paste and Sika Tite-BE	-4.4%	-12.3%		(Kareem et al. 2018)
Calcium carbonate biodeposition		-30 to 35% (fine RCA) -50% (coarse RCA)		(Grabiec et al. 2012)
Microbial carbonate precipitation (at 9.5 pH)		-15%		(Qiu et al. 2014)
Carbonation	+0.47 to 0.56	-22to 28%		(Zhang et al. 2015)

Effect of RCA on asphalt mix

Marshal stability

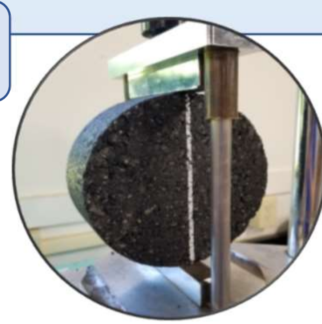
Decrements on RCA consumption above 50%

The highly porous structure of RCA in mix increases the OBC, which fills the voids and its excessiveness develops a thicker bitumen layer around the aggregates which reduced the interlocking leading to a significant reduction in marshal stability values.

Improvement on RCA consumption up to 50%

The densification of RCA incorporated mix due to rearrangement of gradation during mixing and compaction is reason of improved results.

ITS



Decrements on RCA consumption above 20%

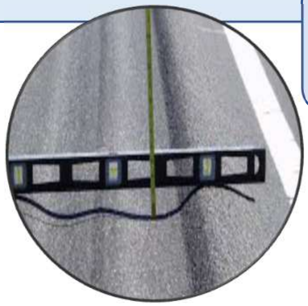
The RCA in bituminous mix absorb more bitumen and decrease the effective binder, causing decreased cohesion.

Improvements on RCA consumption up to 30%

Better internal friction of RCA (as compared to VA), improves the bond between bitumen and aggregates

Effect of RCA on asphalt mix (continued…)

Rutting



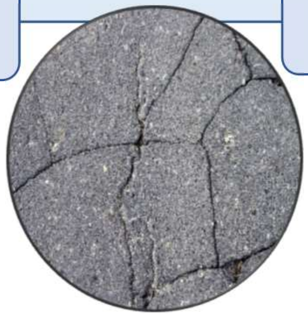
RCA consumption above 30%, susceptible to rutting

The loss of cohesion due to decreased effective binder in RCA incorporated mix and loss of angularity due excessive breaking of RCA are responsible for decreased rutting resistance.

RCA consumption 30-60 %, improve rutting resistance

The residual cementing activity of unhydrated cement particle on RCA's surface increased the cohesion and friction in the mix, which is responsible for increased rutting resistance.

Fatigue



RCA consumption above 50%, susceptible to fatigue

The excessive breaking of RCA particle during mixing and compaction decreases the interlocking and it is found responsible for decreased results.

RCA consumption of 30-50%, improved the fatigue resistance.

The rearrangement of gradation during mixing and compaction, increasing the filler content in RCA incorporated mix, fills the voids and more interlocked mix is produced compared to conventional mix, increased the fatigue resistance

Effect of RCA on asphalt mix

Resilient modulus

Decrements on RCA consumption above 75%

Inferior physical properties of RCA are responsible for decreased resilient modulus of mix.

Improvement on RCA consumption of 30-70 %

Residual cementing activity of RCA are responsible for decreased resilient modulus.

Moisture susceptibility

RCA consumption above 50%, susceptible to moisture

The absorbed water on RCA surface separates the bitumen from the aggregates causing stripping. .

Decrease on RCA consumption of 30-50%.

The more penetration of bitumen in rough surface of RCA than VA is responsible for better result.

Low temperature performance

RCA consumption above 50%, susceptible to moisture

Higher porosity of RCA are responsible for the decreased results.

Improves on RCA consumption upto 50%.

Different type of treatment, like silicon resin activation, coating of WCOR over the surface of RCA and addition of cement are responsible for better result.

The effect of treatment methods used for preparation of RCA on RCA incorporated asphalt mix

Treatment method used	Effect on bituminous mix performance	References
Calcination process	• Fulfilled the Stability requirement as per national standard • Enhanced the rutting performance of HMA. • No significant improvement in resilient modulus	(Wong et al., 2007)
Precoating using slag cement paste (optimum thickness: 0.25 mm)	• Fulfilled the Stability requirement as per national standard • Resilient modulus increased on increasing treated RCA • Resistance to moisture damage and rutting decreased on increasing treated RCA; however, fulfilled the requirement as per national standard.	(Lee et al., 2012)
Activation of RCA using organic silicon resin	• Up to 60 % RCA in asphalt treated base, satisfied the requirement of dynamic stability, resistance to water damage and low temperature performance.	(Hou et al., 2014)
Precoating RCA using 5% bitumen emulsion	• Significantly improved the resistance to water damage • Comparable stiffness, rutting and low temperature potential to conventional mix	(Pasandín and Pérez, 2014a)
MCP	• Enhanced the water damage potential. • The bonding strength of asphalt mixture containing treated- RCA increases 55% over that of untreated-RCA.	(Pan et al., 2015)
Lime and acid treatment	• Significantly improved the marshal stability and water damage potential in both treatments.	(Abass and Albayati, 2020)

Effect of fillers/additives/fibres in RCA incorporated asphalt mix

Fillers	Effect on RCA incorporated asphalt mix	References
Lime (1%) and cement (4.75%)	• 60 % RCA with cement gave the highest marshal stability • Up to 40 % RCA with both fillers satisfied the permanent deformation criteria. • No significant improvement in water damage resistance.	(I Pérez et al., 2012)
Cement kiln dust	30% RCA strengthened the subgrade and subbase, resulting in a decrease in overall pavement thickness.	(Brooks and Cetin, 2012)
Loose-form oil palm fibers (to prevent binder drain down) and hydrated limestone powder	Significant reduction of marshal stability after certain incorporation of RCA.	(Pourtahmasb and Karim, 2014)
Cement	It gave significantly better engineering property compared to stone dust in case of marshal stability, rutting and water damage potential.	(Giri et al. 2018)
Cement	Significantly improved the marshal stability, ITS, and resistance to the water damage, rutting and low temperature.	(Zou et al., 2020b)
Cement	Improved the ITS and water damage potential on use of 100% RCA.	(Zou et al., 2020a)
Carbon black	Combination of RCA and carbon black in mix offer improved marshal stability, marshal quotient values, ITS, water damage potential, and resilient modulus.	(Gopalam et al., 2020b)

Conclusions

- The RCA incorporated bituminous mix has several advantages such as preservation of natural resources, lower energy consumption, lower harmful gas emission, and cost benefits. Despite these advantages, inferior performance of RCA incorporated bituminous mixes restricts its field utilization.

- Several researchers have worked on different methods such as treatments of RCA, use of fillers, fibres, and other additives to improve the performance of RCA incorporated bituminous mix. These methods have slightly increased its field utilization but it is still very low.

- The major issues faced by the practitioners and contactors are related with the variability in the RCA quality, energy/resource requirement of treatment methods and lack of standards and guidelines. Several factors like RCA history, particle size, treatment methods, etc. affects the properties of RCA. Depending upon these factors, the quality of RCA can significantly vary. This variability makes it difficult for the practitioner and contractors to adopt specific treatment methods or specific proportions in the field.

- Most of these treatment methods used to improve the properties of RCA incorporated bituminous mixes are not standardized and lack of standard specifications for their field application. Another problem associated with some of these treatment method is their high resource and power consumption nature which negate the economic and environmental benefits of replacing VA with RCA.

Conclusions (conti…..)

- So, more in-depth research on RCA incorporated bituminous mix is required to simplify its mix design procedure, to improve long-term performance, to understand lifecycle environmental and economic benefits and to develop simpler and environmental friendly treatment methods.

- More detailed national and international guidelines/specifications should be provided for the generalization of the RCA utilization in bituminous

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THANK YOU