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Sustainable use of mine waste and tailings with suitable admixture as aggregates in concrete pavements-A review

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Abstract. Utilization of mine waste rocks and tailings in concrete as aggregates will help in sustainable and greener development. The literature shows the potential use of iron ore tailings as a replacement of natural fine aggregates. As natural sand reserves are depleting day by day, there is a need for substitution for sand in concrete. A comprehensive overview of the published literature on the use of iron ore waste and tailings and other industrial waste in concrete is being presented. The effect of various properties such as workability, compressive strength, split tensile strength, flexural strength, durability and microstructure of concrete have been presented in this paper.

Keywords: concrete; iron ore waste and tailings; strength; durability

1. Introduction

Transportation is vital for economical, industrial, social and cultural development of any country. The inadequate transportation facilities retard the process of socioeconomic development of the country. The road network is the only mode of transportation, which gives maximum service to all and is the only mode, which offers the maximum flexibility to travelers in selecting routes, direction, time and speed of travel (Morth 2012a). Road network alone serves the remote areas. The well-being of citizen, economical growth and status of a country is judged by how well organized and efficient the road network is. A wide variety and range of roads is in use all-round the globe. The terrain, topography, population, culture, the function and structural requirements are the factors that decide that type.

Development of a country depends on the connectivity of various places with adequate road network. Roads are the major channels of transportation for carrying goods and passengers. They play a significant role in improving the socioeconomic standards of a region. They are important assets for any nation. In case of India, India is the second largest road network country in the world, with more than 4,699,024 km which includes 96,214 km of national highways and expressways, 147,800 km of state highways and 4,455,010 km of other roads (https://www.cia.gov/library/publications/resources/the-world-factbook/geos/in.html).

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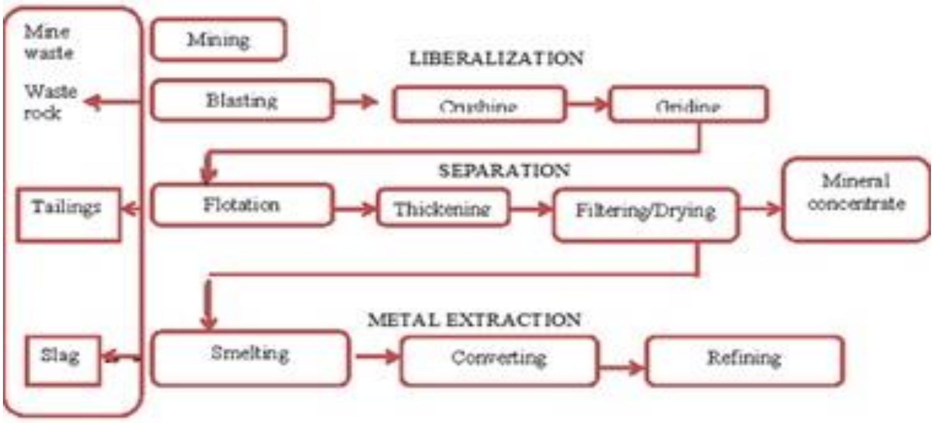

Fig. 1 Mineral extraction from mining to metal (Spitz and Trudinger 2009)

Roads are laid using different materials like gravel, sand, aggregates, bitumen, cement, etc. There has been a constant research to replace or substitute the materials with other materials for better pavement of roads, to reduce the cost, to increase the tyre life, etc. In the process, the waste produced from various sources can be an effective replacement, as the waste will be available at free of cost or with minimum price and on the other hand, handling and disposal of waste also minimizes.

Mining Industry is a basic sector after agriculture. Waste generated from mining includes overburden waste, tailings and other processed waste. Management of mining waste is likely to be of some significance in many developing countries where recycling/extraction and processing of minerals have important economic values. The process of mineral extraction from mining to metal is shown in Fig. 1.

There are two methods of mining, one is open-cast and the other is underground mining. Open-cast mining involves removal of complete waste rock to expose the ore body or coal. The process of removing the waste bound to damage the natural ecosystem by producing various types of pollution like land degradation, air pollution, dust pollution etc. The waste produced is generally dumped outside the mine in the form of overburden dumps. These dumps occupy a large amount of land, which loses its original value and generally gets degraded. Maintaining stability of the dump is also a major issue for the mining industry (Sastry and Ram Chandar 2013). Utilization of such waste rock is being investigated by various researchers for different purposes like building construction materials, pavements, back filling etc. Hence, a partial replacement of the aggregates in concrete by waste rock produced from mines not only saves considerable money in the handling and maintenance of waste dumps but also reduces the cost of construction of roads. In addition, it also reduces the environmental problems at mine site.

The natural reserves or key minerals are to the tune of 82,000Mt such as iron ore, bauxite, dolomite, gypsum, limestone, mica, chromite, manganese, zinc, graphite, etc. India presents significant opportunities in mining and metal space. India has world's 7th largest reserves of iron ore (Indian Chamber of Commerce, May 2015). The production of iron ore in 2014-15 was 129.10 Mt (Annual report 2014-15, Ministry of Mines Govt. of India). Production of such large quantity of ore also increases generation of waste. The waste generated from mining, processing and wastes accumulating at mine sites is shown in Table 1.

Table 1 Reuse and recycling options for mining, processing and metallurgical wastes accumulating at mine sites (Bernd and Lottermoser 2011)

Waste rock		Reuse and recycling option
Mining waste	Waste rock	• Resource of minerals and metals • Backfill for open voids • Landscaping material • Capping material for waste repositories • Substrate for revegetation at mine sites • Aggregate in embankment, road, pavement, foundation and building construction • Asphalt component • Feedstock for cement and concrete • Sulfidic waste rock as soil additive to neutralize infertile alkaline agricultural soils
	Mine water	• Dust suppression and mineral processing applications • Recovery of metals from AMD waters • Drinking water • Industrial and agricultural use • Coolant or heating agent • Generation of electricity using fuel cell technology • Engineered solar ponds to capture heat for electricity generation, heating, or desalination and distillation of water
	Mine drainage sludge	• Extraction of hydrous ferric oxides for paint pigments • Extraction of Mn for pottery glaze • Flocculant/adsorbant to remove phosphate from sewage and agricultural effluents
Processing waste	Tailings	• Reprocessing to extract minerals and metals • Waste reduction through targeted extraction of valuable minerals during processing • Sand-rich tailings mixed with cement used as backfill in underground mines • Clay-rich tailings as an amendment to sandy soils and for the manufacturing of bricks, cement, floor tiles, sanitary ware and porcelains • Mn-rich tailings used in agro-forestry, building and construction materials, coatings, cast resin products, glass, ceramics and glazes • Bauxite tailings as sources of alum • Cu-rich tailings as extenders for paints • Fe-rich tailings mixed with fly ash and sewage sludge as lightweight ceramics • Energy recovery from compost-coal tailings mixtures • Phlogopite-rich tailings for sewage treatment • Phosphate-rich tailings for the extraction of phosphoric acid • Ultramafic tailings for the production of glass and rock wool • Carbon dioxide sequestration in ultramafic tailings and waste rocks

Table 1 Continued

Metallurgical waste	Bauxite red mud	• Treatment of agricultural and industrial effluents • Raw material for glass, tiles, cements, ceramics, aggregate and bricks sequestration • Treatment of AMD waters • Carbon dioxide
	Historical base metal smelting slags	• Production of concrete and cement • Use as fill, ballast, abrasive and aggregate • Extraction of metals (e.g., Cu, Pb, Zn, Ag, Au)
	Phosphogypsum	• Soil amendment • Building and construction material • Extraction of elements and compounds (e.g., U, Y, REE and calcium sulphate)

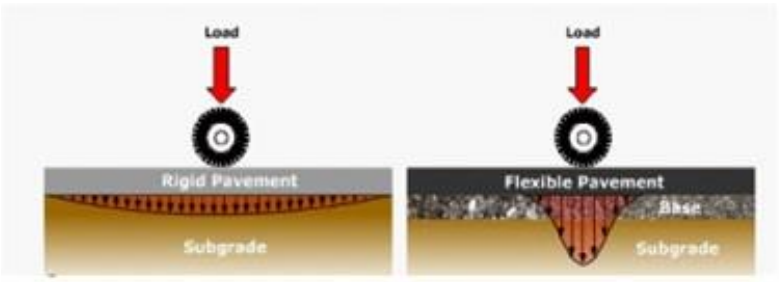

Fig. 2 Deflection of rigid and flexible pavement

2. Rigid pavements

Concrete is the most versatile construction material in use all over the world. Concrete pavements are well known rigid pavements. Concrete roads, on techno-economic considerations, are superior to bituminous roads and will prove to be sustainable in future road construction. Many researchers are in the opinion that, concrete roads should be given serious consideration for arteries of the national road network, which carry a high volume of traffic with an increase in axle loads (Chakravarthy and Kadiyali 1989, Battacharya 2005). Concrete roads are more attractive in the case of expressways, bypasses and urban roads. Concrete roads are also preferable for coastal areas bound by hills having high rainfall, more curves and for high and low traffic rural roads (Bhattacharya 2005).

Concrete roads have a number of advantages over bituminous roads. Concrete roads do not deflect under heavy loads like flexible pavements (Fig. 2). Hence, vehicles require less energy (fuel requirement) while travelling on concrete roads. As per the trials carried out by Central Road Research Institute (CRRI), trucks consume 15-20% less fuel on concrete roads (CMA 2007). Heavy trucks get up to 20% better mileage on concrete surfaces. The concrete roads require very little maintenance (CPAM 2012). Increased speed of vehicles on concrete road reduces congestion and traffic jams. The concrete roads are neither damaged by rain nor distorted by excessive heat.

The construction of modern highways requires huge amount of natural resources such as stone and natural sand. The design life of bituminous roads may be 10 years with proper maintenance, which create a huge burden on natural resources (CMA 2007). Concrete roads will have longer maintenance-free life which reduces the impact on nature. Concrete pavements reflect 33-50% more light than asphalt surface (CAC 2012). It offers a better visibility on rainy nights (CPAM 2012). Concrete provides better and durable skid resistance. Hence, they provide safety for the drivers. It is generally less slippery in wet weather than bituminous pavement (CPAM 2012). Concrete pavements promote utilization of industrial by-products like fly ash and slag (Naik 2008).

Over the years, concrete pavement design has become a more important part for promotion of concrete roads. A high initial investment has to be motivated and the benefits of a pavement with less maintenance over a design life (generally designed for 30-40 years), have to be proved before construction. Efforts are to avoid premature performance failure of concrete roads at a larger degree and to consider the other pavement alternatives as rehabilitation techniques are expensive. The design methodology has to take into account the change of environmental conditions as well as traffic growth. The optimal utilization of materials in the pavement structure demands for long term fatigue resistance at the lower cost and eco-friendly material.

3. Mine waste

Along with growth of mankind, the mining industry has also grown in parallel to supply the raw material for various purposes along with infrastructure development. There are two methods of mining, namely surface mining (Fig. 3) and underground mining. In surface mining, the overburden will be removed and dumped aside, thus waste produced will be much higher than the coal or ore extracted based on stripping ratio. Almost every coal as well as metal mining produces waste rock. The quantity of waste produced (shale and sandstone) in coal mines is in-terms of millions of cu.m per year. Sandstone is a highly porous rock and the strength is medium, so it may not be suitable for pavements. On the other hand, iron ore waste will have better strength, which can be used for pavements and it is also available in large quantity.

3.1 Iron ore waste and tailings

Iron is the world's most commonly used metal - steel, for which iron ore is the raw material, representing almost 95% of all metals used per year (Ramanaidou and Wells 2014). It is used

Fig. 3 A typical view of a surface mine in southern India

Table 2 Production trend of Iron Ore Tailings (IBM-Statistical profile of minerals, 2015-16)

Parameter	2011-12	2012-13	2013-14	2014-15	2015-16
Quantity (Th. Tonnes)	168582	136618	152183	129321	155910
Value (Rs. '000)	383570264	328244402	316491777	276636789	221158219

primarily in structural engineering applications and in marine purposes, automobiles and general industrial applications (machinery).

World production averages two billion metric tons of raw ore annually. The total recoverable reserves of iron ore in India are about 9,602 million tons of hematite and 3,408 million tons of magnetite. World consumption of iron ore grows 10% per annum on average with the main consumers being China, Japan, Korea, the United States and the European Union (https://en.wikipedia.org/wiki/Iron_ore). Processing of such large quantity of iron ore produces good amount of tailings. The production trend of Iron Ore Tailings in India for the past 5 years is shown in Table 2

The different types of mine waste are:

√ Overburden: The soil and rock removed to gain access to the ore deposits in open pit mines are known as overburden. It is piled on the surface at mine sites where it will not disturb further expansion of the mining operation as moving large volumes of material is expensive.

√ Waste rock: Waste rock is a material that contains mineral in concentration considered too low to be extracted economically. The waste rock is suitable for earthworks on the site during mining operations and as aggregates for concrete works.

√ Tailings: Tailings are mineral waste products and finely ground rock of mineral processing operations. It also contains leftover of processing chemicals and is deposited in the form of water based slurry into tailing ponds. The tailings are difficult to utilize due to its finer grain size, but can be utilized in selective operations. Based on the type of tailings pond, the water can be drained so that the remaining waste can be dried.

The main condition of mine waste utilization is that the materials should satisfy all the geotechnical criteria and is environmental friendly. A thorough characterization of mine waste is essential as it must not be a source of contamination. The value of utilization of mine waste can be enhanced on the basis of geotechnical properties and environmental constraints.

The suitable possibilities for utilization of mine waste rock are:

√ Road constructions and construction material for building industry
√ Material for landfill and for embankments designed for mitigating traffic noise
√ Material to stabilize pit walls or tunnels and to backfill stopes and galleries
√ Material for landscaping and stabilization during mine closure
√ Material in the neutralization of acidic groundwater generated in the mine pit
√ Tailings dams and as fertilizer or supplement to enhance soil quality/fertility.

On the other hand, the natural resources (like sand) are becoming scarce and expensive due to the excessive cost of transportation and large scale depletion of river sand creating serious environmental problems. Restrictions are made for the collection of river sand from the river bed and some of the states have banned sand mining forcing concrete industry to look for alternative materials of river sand. Research is therefore required to investigate the use of cheaper, easily available and sustainable alternative materials to natural river sand (Bederina *et al*. 2013).

Various researchers have studied the utilization of iron ore waste and tailings in various aspects including replacement of sand, aggregate or cement in concrete. A brief summary of the work carried by some researchers, is given below.

The waste produced from various stages of mining is to be disposed in an environmental friendly manner. It should not cause any land pollution, water pollution, air pollution, etc. The waste dump yards should be stable. In-order to avoid the environmental issues arising from the disposal of these wastes, it is better to use them for some other purposes.

Juwarkar *et al*. (2003) studied the physico-chemical properties on the Codli mines wastes of Goa and suggested that the mine wastes are harmful in plant growth supportive nutrients and hence pose danger when they are mixed with the agricultural soil.

Skarzynska (1995b) found that mining industry had used the iron ore waste in various small engineering structures, essentially in close proximity to the mines. It was found that, there was an increase in the use of iron ore waste as a construction material for embankments of roadways, railways, rivers and dams instead of using natural soil. Iron ore waste is widely used in land reclamation and backfilling of quarries (Skarzynska 1995b).

3.2 Replacement for fine aggregates

Iron ore tailings (IOT) comprise fine materials, mainly containing silica, together with iron oxides, alumina and other minor minerals. This constitution indicates their potential as construction material, such as aggregate for mortar and concrete (Yellishetty *et al*. 2008, Huang, *et al*. 2013, da Silva *et al*. 2014).

The comprehensive utilization of iron ore tailings (IOT) has received increasing attention all over the world. The major utilization of IOTs includes land reclamation (Maiti *et al*. 2005), re-extraction of iron or other metals using advanced technology (Li *et al*. 2010, Sirkeci *et al*. 2006), and as raw ingredients in producing infrastructure materials, backfilling materials and fertilizers (Zhang *et al*. 2006, Zhu *et al*. 2011).

Wang and Wu (2000), Zheng *et al*. (2010) reported utilization of tailings in clinker and concrete respectively. Iron ore tailings used as replacement of sand in concrete (Cai *et al*. 2009), as siliceous materials in ceramics (Liu *et al*. 2009, Das *et al*. 2000) and autoclaved aerated concrete (Li *et al*. 2011). The use of IOTs in the production of infrastructure materials promotes the sustainability of the mining industry and simultaneously enhances the greenness of the construction industry by reducing the demand for raw materials like river sand.

Ravi Kumar *et al*. (2012) investigated the properties of Interlocking Concrete Block Paver (ICBP) mixed with Iron Ore Tailings (IOT) as partial replacement of cement. For M25 grade of concrete, by varying the percentage of iron ore tailings, it resulted in an increase in compressive strength with IOT 5% to 15% and decrease in compression strength for IOT 15% to 25%.

Sun *et al*. (2011) investigated the properties of cement stabilized iron ore tailing gravel as a highway construction material by performing various experiments and resulted in higher strength, rigidity, good water stability and frost resistance. When the cement content was more than 5.5%, 7 days-age compressive strength of cement stabilized iron ore tailing gravel is more than 2.5 MPa. So, it can be used as sub-base course material for heavy duty traffic asphalt pavement and base course material of low duty traffic asphalt pavement.

Zhao *et al*. (2014) conducted an experimental study for the replacement of sand with iron ore tailings to prepare UPHC (Ultra High Performance Concrete). When the replacement level was not more than 40% for 90 days standard cured specimen, the mechanical behavior of the tailings was comparable to that of the control mix and the compressive strength decreased by less than 11% and flexural strength increased by 8% in comparison to control mix for specimen that were steam

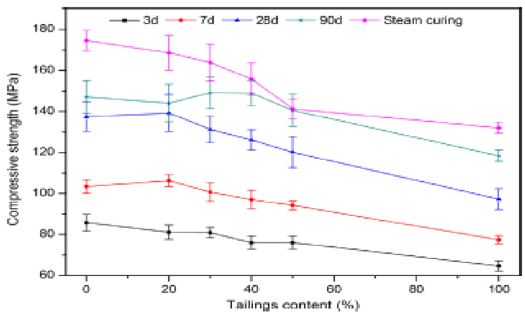

Fig. 4 Compressive strength results of UHPC mixes under different curing regimes (Zhao *et al*. 2014)

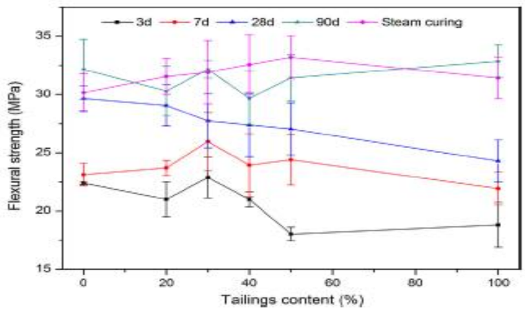

Fig. 5 Flexural strength results of UHPC mixes under different curing regimes (Zhao *et al*. 2014)

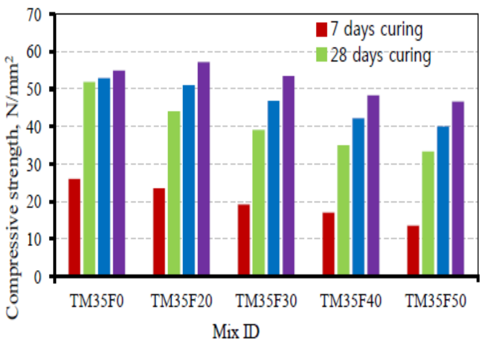

Fig. 6 Average compression strength of concrete at 7, 28, 56 and 90 days of curing with 35% TM and varying percentage of FA. (Sunil *et al*. 2015)

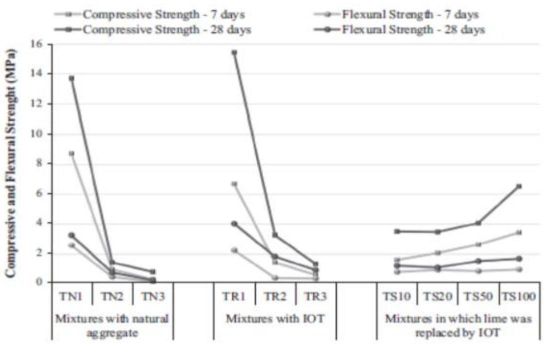

Fig. 7 Compressive strength and flexural strength of mortars with natural aggregates, IOT and with lime replaced by IOT (Wanna *et al*. 2016)

cured for 2 days. Fig. 4 and Fig. 5 show the compressive and flexural strength of UHPC mixes under different curing regimes.

Duan (2016) investigated the fresh properties, residual strength, mass loss and microstructure advancement of geopolymer prepared by using fly ash as start material with IOT and activated by sodium silicate and sodium hydroxide solutions after exposure to different thermal cycles at various heating temperatures when fly ash was partially replaced with IOT at levels ranging from 0%-30% by weight. The results indicated, decrease in compressive strength after 7 thermal cycles and loss in compressive strength increased as the cycle target temperature increased from 200° to 800℃. If the replacement with IOT less than 30%, it improves the thermal resistance of geopolymer. Replacing of fly ash with 20% IOT leads to a reduction of the porosity and micro cracking resulting in much denser microstructure.

The effect of replacing fine aggregate by Tailing Material (TM) and cement by Fly Ash (FA) on a standard size specimen for mechanical properties were evaluated (Sunil *et al*. 2015). The concrete mix of M40 Grade was adopted with the water cement ratio equal to 0.40. It resulted in good strength properties with 35% replacement of fine aggregates with TM and it was observed that with 20% replacement of cement with FA resulted in an increase in strength properties (Fig. 6).

Recent trends in autoclaved aerated concrete (AAC) have heightened the need for industrial waste utilization in AAC production. Several researchers have investigated the possibility of replacing the traditional raw materials of AAC by industrial waste, such as fly ash (Andre *et al*. 1999), air-cooled slag (Mostafa 2005), coal bottom ash (Kurama *et al*. 2009), efflorescence sand (Mirza and Al-Noury 1986), copper tailings (Huang *et al*. 2012) and carbide slag (Fan *et al*. 2014), etc.

AAC was developed using the coal gangue and the iron ore tailings. The dry mixture proportion of the optimal AAC with a bulk density of 609 kg/m^3 and compressive strength of 3.68 MPa was 20% CGC, 40% iron ore tailings, 25% lime, 10% cement, 5% desulphurization gypsum and 0.06% aluminium powder. From this dry mixture, slurry with 56% water was made (Wang *et al*. 2016).

Ma *et al*. (2016) recommended the technological parameters for preparing light weight iron tailings AAC blocks- cement 8%, quicklime 21% to 27%, 20 minutes ball milled siliceous 62% to 68% (with 40% to 60% substituted by iron tailings), gypsum 3%, W/R 0.6, Al powder 0.14% and at 1.4 MPa steam pressure maintaining for 8hours. Under this condition, the bulk density obtained was between 490 and 525 kg/m^3, compressive strength higher than 2.5 MPa. According to the result of the leaching test, the iron tailing AAC blocks are not harmful to the environment. Hence, it is applicable to manufacture AAC blocks with iron tailing.

The technical feasibility of using iron ore tailings from tailing dams (IOT) as construction material, mortar for laying and coating was determined by Wanna *et al*. (2016). Three mixtures were produced such as conventional mortars, mortars with complete replacement of natural aggregates by IOT and mortars replacing lime by IOT in proportions from 10% to 100%. Characterization of mortars and IOTs were made and it resulted in increase in bulk density, reduced levels of incorporated air, an increment in the amount of mixing water and improved mechanical properties when compared with conventional mix (Fig 7).

Ali *et al*. (2016) investigated the strength and durability properties of concrete incorporating maximum IOT as a replacement for river sand. The specific gravity is 2.6, relative density is 1.27 gm/cm^3, fineness modulus=1.05 and the water absorption rate is 7%. Fig. 8 a&b shows the Field Emission Scanning Electron Microscopy (FESEM) at different magnification for IOT. The result from SEM analysis showed that, it considered irregular and porous shaped particles which were well dispersed. The high surface area and water demand resulted due to the irregular shaped particles coupled with loose ones. The particle size distribution indicated that IOT are fine particles and fall to medium grade quality. The compressive strength of the IOT concrete specimen

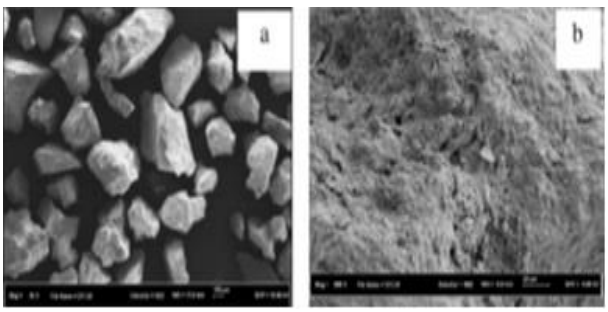

Fig. 8 FESEM of IOT at (a) 25 lm and (b) 500 lm magnifications (Ali *et al*. 2016)

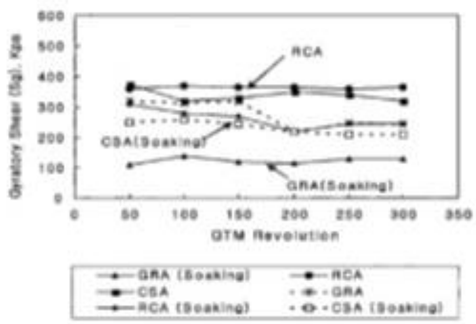

Fig. 9 Comparison of gyratory shear of RCA, CSA and GRA (Park 2003)

were higher than the control mix for all the curing periods and w.r.t to 28 days curing, the percentage increase was 12.9%, 10.5%, 10.2% and 1.3% for replacement levels at 25,50,75 and 100% IOT respectively. Hence 25% IOT replacement for natural sand gave highest strength and is considered as optimum mixture.

3.3 Replacement for coarse aggregates

Yellishetty (2008) used iron ore waste from Goa and conducted an experimental study. In the concrete mix, 40% of coarse aggregates were replaced with iron ore tailings and concrete blocks were made for 28 days curing. It resulted in the compressive strength of 21.93MPa to that of granite aggregate of 19.91 MPa. Hence, the increase in the compressive strength was noticed with iron ore tailings with respect to the conventional coarse aggregate.

Park (2003) considered three different aggregates, those are, recycled concrete aggregate (RCA), crushed stone aggregate (CSA) and gravel (GRA) and conducted laboratory study with Gyratory Testing Machine and field study with the falling weight deflectometer to investigate the characteristics and performance of dry and wet recycled concrete aggregates (RCA) as a base and sub base materials for concrete pavements. The physical properties of the RCA were investigated in terms of moisture-density relationship, particle index and fine aggregate angularity. Performance concerns have focused on compactibility, stability, shear resistance and particle breakage of the RCA. It resulted in the compactibility of RCA same as that of CSA and GRA. Breakage of aggregate particles increased in severity from GRA to RCA. The stability and the shear resistance of the RCA in wet conditions are lower than dry conditions (Fig. 9), however, the reduction rate is comparable with observed values in CSA and GRA. The deflection of the RCA section using the FWD in the field was similar to that of CSA section.

Arora and Singh (2016) conducted experiments to obtain the flexural fatigue life of concrete beam specimens made with 100% recycled concrete aggregates (RCA) as well as 100% natural aggregates (NA) under different stress levels. Specimens of size 100 mm×100 mm×500 mm were tested under four point flexural fatigue loads applied at a frequency of 10 Hz. It has been shown that the fatigue life distribution of concrete mixes made with 100% RCA and 100% NA can be modeled by the two-parameter Weibull distribution. The values of the shape parameters of the

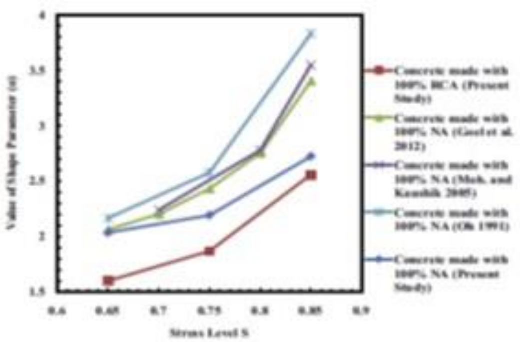

Fig. 10 Comparison of shape parameter ‘α’ of concrete made with RCA with presentand previous studies on concrete madewith NA (Arora and Singh 2016)

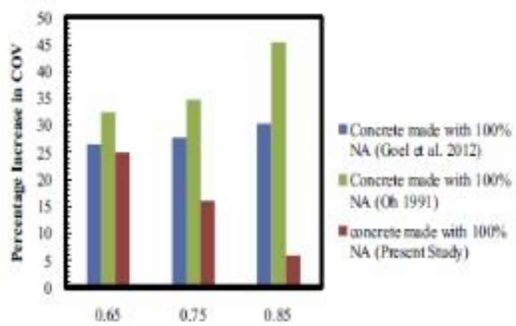

Fig. 11 Percentage increase in coefficient of variation (COV) of concrete made wit RCA with respect to present and previous data on concrete made with NA (Arora and Singh 2016)

Weibull distribution obtained for concrete made with RCA have been found to be smaller than that of concrete made with NA in this investigation (Fig. 10 and Fig. 11), thus indicating higher variability in the distribution of flexural fatigue life of concrete made with RCA viz., concrete made with NA. The two-million cycle endurance limit for concrete made with 100% RCA has been found to be 50%, which is about 8% and 7% lower than that of concrete made with NA in present and previous studies respectively.

Batayneh and Asi (2007) used waste materials like glass, plastics and demolished concrete to be recycled for their study. Ground plastics and glass were used to replace up to 20% of fine aggregates in concrete mixes, while crushed concrete was used to replace up to 20% of coarse aggregates. To evaluate these replacements on the properties of the OPC mixes, a number of laboratory experiments such as workability, unit weight, compressive strength, flexural strength and indirect tensile strength were conducted. When up-to 20% of plastic and crushed concrete was used in concrete, the strength of the concrete exhibited lower compressive and splitting-tensile strength than that of normal concrete using natural aggregates. Therefore, it is recommended that concrete with recycled materials of lower strength to be used in certain civil engineering applications, especially in non-structural applications, where lower strength up to 25 MPa is required. This will contribute to cutting down the cost of using non-structural concrete. Hence, they concluded that the three types of waste materials could be reused successfully as partial substitutes for sand or coarse aggregates in concrete mixtures.

Kumar *et al*. (2016) made experimental investigations for quartz sandstone as a replacement for coarse aggregate in concrete. M30 grade concrete was designed with water cement ratio of 0.4. Replacement of coarse aggregates was considered from 0-100% compared to the control mix and tests were conducted to determine compressive strength, flexural strength, abrasive resistance, permeability and sorptivity in concrete samples. It was observed that 40% replacement of quartz sandstone in coarse aggregates achieved target strength of 38.25 N/mm^2. At 100% replacement of quartz sandstone for 0.45 w/c ratio, the maximum abraded depth of 1.89 mm (Fig. 12) was obtained and permeability and sorptivity increased to a maximum of 0.46 mm (Fig. 13).

Anderson *et al*. (2016) investigated a scheme by replacement of coarse aggregate concrete with three different wastes, ceramic tile materials in replacement ratios 20%, 25%, 35%, 50%, 65%, 75%, 80% and 100%. The compressive strength decreased by 4.3% and 5.6% and flexural strength decreased by 17.9% with 100% floor and wall tile replacement respectively compared with reference mix. The elastic modulus of elasticity increased by 26.9% compared to 21.6 GPa measured in the reference concrete. Hence, the results show that waste ceramic as a possible

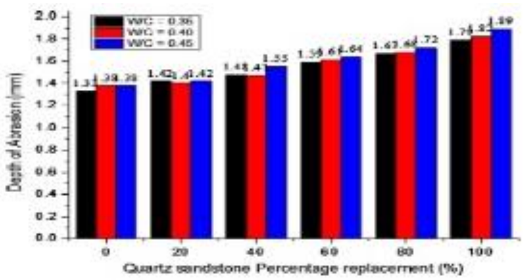

Fig. 12 Graphical representation of depth of wear vs quartz percentage replacement (Kumar *et al*. 2016)

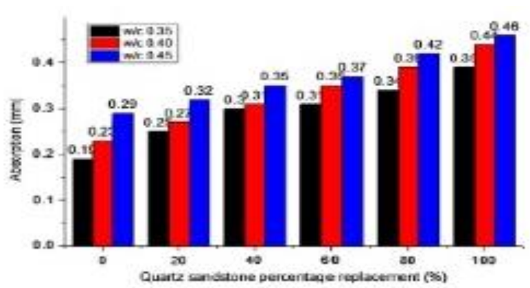

Fig. 13 Water absorption (Sorptivity) of concrete containing quartz sandstone aggregate (Kumar *et al*. 2016)

practicable natural coarse aggregate replacement material with minimal changes in mechanical properties.

The allowable disposal method for iron tailings is outdoor stack after solidifying with a curing agent, which may cause soil contamination, river and underground water pollution and potential danger (Dudka and Adriano 1997, Licsk *et al*. 1999, Moreno and Neretnieks 2006). Thus, for environmental protection and sustainable development, utilization of iron tailings has become an issue. Many studies engaged in utilizing iron tailings such as recovery (Sirkeci *et al*. 2006, Das *et al*. 2002), fired blocks (Yang *et al*. 2014), ceramsite (Das *et al*. 2000), concrete aggregate (Zhao *et al*. 2014).

Few other waste materials used as a partial replacement of cement and aggregates in concrete by previous researchers are discussed below;

3.4 Other industrial waste considered for replacement for cement and fine aggregates

The effect of different micro-silica (MS) contents of 5, 10 and 15% by weight as partial replacement of cement on mechanical and durability properties of high volume fly ash- recycled aggregate concrete (HVFA-RAC) containing 50% class F fly ash (FA) and 35% recycled concrete aggregates (RCA) as partial replacement of cement and coarse aggregates respectively was studied. The study established that MS contributes to the sustainability of HVFA-RAC significantly by improving the mechanical and durability properties of concrete (Faiz Shaikh *et al*. 2015).

Kiran *et al*. (2014) studied the strength aspects of Self Compacting Concrete (SCC) prepared by partial replacement of cementitious materials by Red Mud (RM) at 1%, 2%, 3% and 4% and in the same mix by partially replacing sand by Iron Ore Tailings (IOT) at 10%, 20%, 30% and 40%. The compressive strength and flexural strength achieved was found to be more than the conventional mix at 2% RM and 30% IOT. Ram Chandar *et al*. (2016a, 2016b) partially replaced sand with laterite and sandstone respectively, and found that though there is not much improvement on strength properties of concrete yet these can be used as a replacement for sand.

Influence of partial replacement of sand with limestone waste (LSW), with marble powder as an additive on the concrete properties was investigated by Omar *et al*. (2012). The replacement of sand with limestone waste at varying percentages of 25%, 50% and 75% in concrete mixes and 5%, 10% and 15% marble powder were used in the concrete mix. The mechanical properties of fresh and hardened concrete with the effect of limestone as replacement for fine aggregates were investigated using compressive, indirect tensile strength, flexural strength, modulus of elasticity and permeability. The result shown that, the limestone waste as fine aggregate enhanced the slump test of the fresh concrete and unit weight concrete were not affected and the compressive strength increased by 12% for 28 days (Tables 3 and 4). It was observed that the performance was good when the limestone waste as fine aggregate was used in presence of marble powder.

Waste foundry sand and bottom ash was used as partial replacement of fine aggregates in equal quantities in various percentage (i.e., 0-60%) on concrete mechanical properties such as compression, split tensile and flexural strength and durability characteristics viz., rapid chloride penetration and deicing salt surface scaling of the concrete along with the micro-structural analysis with XRD and SEM was determined and the compressive strength resulted in the range of 29-32 MPa, splitting tensile strength was in the range of 1.80-2.46 MPa and flexural strength was in the range of 3.95-4.10 MPa on the replacement of fine aggregates from 10-50% with the interval of 10%. It was further observed that with the replacement of around 30% of the natural fine

Table 3 Result of compressive strength for specimens Phase 1 (350kg/m^3)

Mix symbol	% (LSW)	% (M.P)	Compressive strength (MPa)		
			7 days	28 days	90 days
N^*_{-350}	0	0	26.2	33.5	36.7
$N_{25\text{-}350}$	25		27.9	38.1	39.7
$N_{50\text{-}350}$	50		29.3	37.7	40.9
$N_{75\text{-}350}$	75		28.1	31.8	35.2
$M_{1\text{-}350}$	0	5	29.3	35.2	38.4
$M_{2\text{-}350}$		10	31.7	39	42.3
$M_{3\text{-}350}$		15	33.7	40.6	44.5
$M_{4\text{-}350}$	25	5	31.1	38.5	41.6
$M_{5\text{-}350}$		10	36.2	42.2	44.8
$M_{6\text{-}350}$		15	38.8	44.1	46.5
$M_{7\text{-}350}$	50	5	31.2	38.3	41.9
$M_{8\text{-}350}$		10	34.9	41.7	44.3
$M_{9\text{-}350}$		15	36.5	43.6	46.4
$M_{10\text{-}350}$	75	5	28.5	35.5	37.2
$M_{11\text{-}350}$		10	30.1	38.6	41.6
$M_{12\text{-}350}$		15	31.2	40.7	43.4

Table 4 Result of compressive strength for specimens Phase 2 (450kg/m^3)

Mix symbol	% (LSW)	% (M.P)	Compressive strength (MPa)		
			7 days	28 days	90 days
N^*_{-450}	0	0	29.7	41.7	45.8
$N_{25\text{-}450}$	25		31.5	41.9	48.4
$N_{50\text{-}450}$	50		28.9	40.3	45.2
$N_{75\text{-}450}$	75		27.1	38.2	44.3
$M_{1\text{-}450}$	0	5	35.5	44.1	49.7
$M_{2\text{-}450}$		10	37.9	48.4	52.8
$M_{3\text{-}450}$		15	40.7	51.2	56
$M_{4\text{-}450}$	25	5	36.4	44.3	50.3
$M_{5\text{-}450}$		10	37.1	46.9	53
$M_{6\text{-}450}$		15	39.8	50.2	55.1
$M_{7\text{-}450}$	50	5	33.6	43.4	46.9
$M_{8\text{-}450}$		10	36.4	46.8	50.1
$M_{9\text{-}450}$		15	37.8	48.4	53.2
$M_{10\text{-}450}$	75	5	31.5	42.5	46.5
$M_{11\text{-}450}$		10	33.1	46.9	48.8
$M_{12\text{-}450}$		15	35	49.1	51.8

aggregates with the industrial by-product aggregates there was increase in compressive, splitting tensile strength and flexural strength compared to the conventional concrete (Siddique 2014).

After going through a detailed literature review, it was found that a combination of iron ore waste and tailings for replacement of aggregates in construction of pavements is not yet fully explored.

Further, to increase the durability and strength of concrete, admixtures can be used accordingly. A brief introduction of admixture with the study made by previous researchers is discussed in the next section.

3.5 Admixture

Admixtures are the ingredients in concrete other than Portland cement, water and aggregate that is added to the mix immediately before or during mixing. Admixtures are used primarily to reduce the cost of concrete construction, to modify the properties of hardened concrete, to ensure the quality of concrete during mixing, transporting, placing and curing.

Admixtures can be classified by function as follows:

√ Air-entraining admixtures
√ Water-reducing admixtures
√ Plasticizers
√ Accelerating admixtures, Retarding admixtures, Hydration-control admixtures
√ Corrosion inhibitors
√ Shrinkage reducers
√ Alkali-silica reactivity inhibitors
√ Coloring admixtures

Miscellaneous admixtures such as workability, bonding, damp proofing, permeability reducing, grouting, gas-forming, antiwashout, foaming, and pumping admixtures.

The effectiveness of an admixture depends on several factors including: type and amount of cement, water content, mixing time, slump and temperature of the concrete. Sometimes, effects similar to those achieved through the addition of admixtures can be achieved by altering the concrete mixture-reducing the water-cement ratio, adding additional cement, using a different type of cement or changing the aggregate and aggregate gradation.

One such type of admixture is bonding admixture. They are usually water emulsions of organic materials including rubber, polyvinyl chloride, polyvinyl acetate, acrylics, styrene butadiene copolymers and other polymers. They are added to Portland cement mixtures to increase the bond strength between old and new concrete. Flexural strength and resistance to chloride-ion ingress are also improved. They are added in proportions equivalent to 5% to 20% by mass of the cementing materials; the actual quantity depending on job conditions and the type of admixture used. Some bonding admixtures may increase the air content of mixtures. Non reemulsifiable types are resistant to water, better suited to exterior application and used in places where moisture is present (http://www.ce.memphis.edu/1101/notes/concrete/PCA_manual/Chap06.pdf).

One of the admixtures used in concrete to increase the durability and toughness of concrete is recycled rubber tyres. They are used as partial replacement of sand in the form of crumb rubber and tire derived aggregates as partial replacement of coarse aggregates. The statistics of the recycled rubber produced and the research work reported by previous researchers regarding the feasibility and properties when used in concrete are discussed below.

3.5.1 Perlite

Perlite is a siliceous volcanic rock, whose volume can expand substantially under the effect of

Table 5 Various applications of perlite along with their percentage of usage (USGS Mineral Commodity Summaries 2011, 2013)

Estimated perlite consumption in U.S. by application	
Percentage	Use
53	Building construction products
14	Horticultural aggregate
14	Fillers
8	Filter aid
11	Other

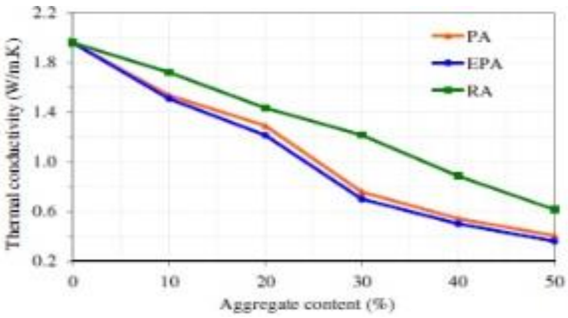

Fig. 14 Effect of EPA, PA and RA content on the thermal conductivity (Oktay *et al*. 2015)

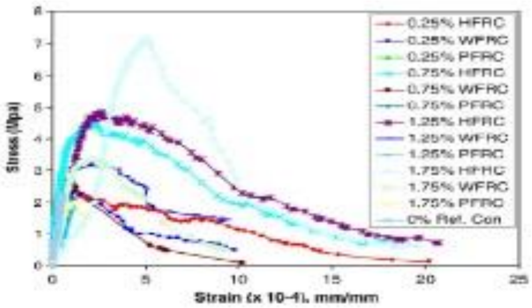

Fig. 15 Flexural strength vs. strain for fiber reinforced concretes (Gul *et al*. 2007)

heat. When heated above 870℃, its volume increases 4-20 times of the original volume (Chandra and Berntsson 2002). The world reserves of perlite are estimated at 700Mt (https://en.wikipedia.org/wiki/Perlite). As a result of this volume increase and its porous structure, water absorption of the expanded perlite is significantly high. In addition, the density of expanded perlite is very low compared to that of normal perlite. Perlite is being used in different applications as shown in Table 5.

Compared to other materials such as exfoliated vermiculite, expanded clay or shale, pumice, mineral wool, competitive price of expanded perlite may be an important advantage.

Sengul *et al*. (2011) replaced normal aggregate with the expanded perlite and it was observed that the thermal conductivity of the mixtures reduced substantially. The compressive strength and modulus of elasticity of concrete reduced. Due to strength loss, concrete produced with more than 20% expanded perlite can be classified as insulation concretes. The air dry density of the concrete was reduced to a minimum of 392 kg/m^3. Both water absorption and sorptivity increased with higher quality of expanded perlite.

Oktay *et al*. (2015) made different types of concrete containing silica fume (SF), superplasticizer (SP) and air-entrained admixtures with a constant water-cement ratio, and normal aggregates replaced by lightweight aggregates (LWAs) including pumice (PA), expanded perlite (EPA) and rubber aggregates (RA) at different volume fractions of 10%, 20%, 30%, 40% and 50%. i.e., reductions at 28-day were 39.80, 63.33, 80.69, 84.29 and 90.58, and 35.46, 54.89, 74.80, 80.90 and 81.66 percent for 10%, 20%, 30%, 40% and 50% EPA and PA, respectively and reduction by 18.91%, 41.35%, 63.28%, 81.65% and 91.26% were observed when 10%, 20%, 30%, 40% and 50% of the normal aggregate was replaced by an equivalent volume of RA, respectively.

It is also resulted in improved insulation characteristics of the composite concretes. Furthermore, it was found that the reduction in thermal conductivity and diffusivity of the produced samples reached to 82% and 74% respectively (Fig. 14).

Gul *et al*. (2007) investigated the possibilities of using the raw perlite aggregate (RPA) replacement normal aggregate (NA) in concrete by studying the effect of hooked steel, wavy steel and polypropylene fibers on thermo-mechanical properties of lightweight concrete produced from 100% RPA. With the increase in the steel fiber ratio in the mixtures, unit weight, compressive strength, splitting-tensile strength and flexural strength of the concrete increased up to 4%, 11%, 143% and 227% respectively (Fig. 15). The increase in the steel fiber ratio leads to a consistent increase in both strength and toughness up to a fiber content of 1.75%.

3.5.2 Other admixtures

Various other admixtures were used to prevent early cracking of slabs, thermal behavior etc., of concrete.

Meagher, *et al*. (2015) made a comparative study and the effect of a calcium chloride-based accelerator and a calcium nitrate-based accelerator in rapid strength concrete mixtures on the early age cracking potential of concrete repair slabs. The results showed more shrinkage, higher restraint stresses and higher strength for the calcium nitrate-based accelerator mixture. HIPERPAV software, created under Federal Highway Administration sponsorship, was used to predict the early-age cracking risk for concrete pavements. It simulated a lower cracking risk for the calcium nitrate-based accelerator mixture during evening and nighttime placements and between 5am to 1pm increased the cracking potential. Calorimetry, free shrinkage and rigid cracking frame testing were used with the modeling software to observe trends in these mixtures.

To investigate the thermal behavior of cement matrix with high-volume mineral admixtures at early age, 40% mineral admixtures by mass were added as partial replacement of cement and the cement pastes were casted into a well-sealed plastic cylinder in which no water was transferred to the environment, the drying shrinkage being prevented. In addition, pseudo-adiabatic condition of mass concrete was simulated by covering the specimens with heat insulation materials. Results show that with addition of fly ash, coal gangue and blast furnace slag the heat liberation and peak temperature of cement paste decreased, while its total shrinkage increases. There is no shrinkage but expansion of the pastes during the temperature rise process, which may be attributed to the complete compensation of the shrinkage by thermal dilation of the pastes. The thermal dilation coefficient (TDC) of cement paste changes drastically with the hydration duration and it is also related to the addition of mineral admixtures (Liwu and Min 2006).

Zainab *et al*. (2008) determined the efficiency of reusing waste plastic in the production of concrete and replacement of sand in concrete with recycled waste by 0%, 10%, 15% and 20%. The laboratory tests were performed with curing ages of 3,7,14 and 28 days to determine the slump, fresh and dry density and compressive strength and it resulted in the decrease of compressive strength with reference to the control mix (Fig. 16). For the concrete mixture made of 20% waste plastic, flexural strength decreased by 30.5% with reference to the control mix (Fig. 17). Therefore the results proved the arrest of the propagation of micro-cracks by introduction of waste plastic of fabriform shapes to concrete mixtures.

Addition of tailings from the concentration of iron ore for the production of red ceramics within 5% is highly feasible as an additive. The addition of iron ore concentration tailings to the ceramic mass resulted in an increase in its flexural strength by 30%, decrease in the density, increase in the porosity and decrease in the water absorption. The results were found desirable to the ceramic

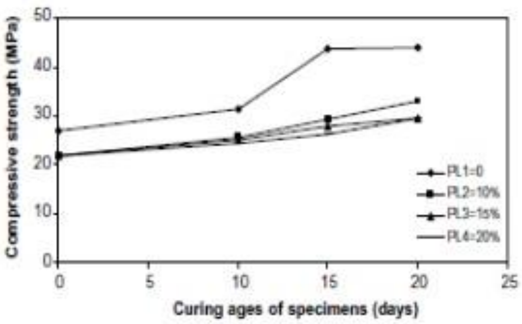

Fig. 16 Compressive strength with waste plastic (Zainab *et al*. 2008)

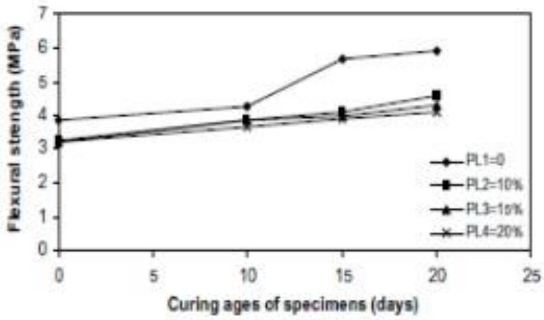

Fig. 17 Flexural strength with waste plastic (Zainab *et al*. 2008)

industry (da Silvaa *et al*. 2014).

Recycled rubber tyre has also been used in concrete as aggregates and as an additive. A brief introduction and previous studies on the utilization of crumb rubber and recycled rubber tyre is discussed below.

Recycled rubber tyre can be used as partial replacement of sand in the form of crumb rubber and tire derived aggregates as partial replacement of coarse aggregates, as lot of waste is generated from automobile industry. India is the third largest producer, fourth largest consumer of natural rubber and fifth largest consumer of synthetic rubber in the world. Indian Rubber Industry plays a core sector role in the Indian national economy. Globally, it is estimated that 13.5Mt of tyres are scrapped every year; 40% of which comes from emerging markets such as China, India, South America, Southeast Asia, South Africa and Eastern Europe. In the US alone, exports of waste tyres amounted to almost 140,000 tonnes/year (http://www.allindiarubber.net/). With the increasing number of cars and trucks all over the world, used tires are also available in large quantities and are extremely cheap for the production of rubber powder. The powder of these used tyres can be used as a substitute of raw material for the production of rubber. This is a recycling process of vehicles tyres that are no longer suitable for use on vehicles due to wear or irreparable damage such as punctures. Granules of rubber can be obtained in various final grain sizes. This has become meaningful because processed rubber is becoming more acceptable in the market due to increasing raw material prices. Waste tyre rubber powder is widely used to build the playground, highway road, etc.

Waste tires are a major environmental problem, with an increasing volume of rubber waste in landfills from the disposal of used tires. The reuse of rubber tires remaining from the retreading process can minimize environmental impacts and help the natural resources. Many researchers have investigated the use of recycled tires mostly relating to applications such as asphalt pavement, waterproofing systems and membrane liners (Siddique and Naik 2004, Cao 2007).

The literature on the use of tire rubber particles in cement-based materials generally focus on using tire rubber particles as coarse or fine aggregate in concrete. Results indicate that the rubberized concrete mixtures possess a lower density, increased toughness and ductility, lower compressive and tensile strength and more efficient sound insulation.

Eldin and Senouci (1993) studied the mechanical behavior of concrete containing rubber tires and showed that the concrete mixtures exhibited lower mechanical strengths but demonstrated a ductile and plastic failure. Moreover, the effect of the rubber particle size on the mechanical properties of concrete has been studied by Topcu (1995), and he observed that despite a decrease in both unit weight and compressive strength, elastic behavior has improved.

Hernandez-Olivares and Baluenga (2004) reported that the addition of crumb tire rubber to high-strength concrete slabs improved fire resistance and reduced the damage by fire. Permeability is the most effective factor in determining concrete durability. An experimental study was carried out by Ganjian *et al*. (2009) to investigate the effect of waste rubber tyre on the water permeability for a single w/c ratio (0.5). It was found that replacing the coarse aggregate by chipped rubber aggregates as well as replacing cement with the powdered rubber (obtained by grinding the crumb rubber) increased the water permeability. This increase in water permeability was attributed to the reduction in bonding between particles in the modified concrete.

Gupta *et al*. (2016) reported that, partial replacement of sand with rubber fibers and partial replacement of cement with silica fume resulted in a decrease in compressive strength, static and dynamic modulus of elasticity. Fig. 18 shows the microstructural analysis, the space in between the rubber fibre and cement paste indicate weak interfaces resulting in reduced strength of rubberized concrete.

It has been reported by Oikonomou and Mavridou (2009) that up to 68% reduction in dynamic modulus of elasticity was observed on 12.5% replacement of fine aggregates by crumb rubber. This reduction in elastic modulus indicates higher flexibility, which can be viewed as a positive gain in rubberized concrete mixtures for application where flexibility is a major concern rather than strength.

Kardos and Durham (2015) prepared sustainable concrete mixtures for pavement applications that incorporated waste-stream materials such as fly ash, crumb rubber and recycled concrete aggregate. Fresh and hardened concrete properties were measured on mixtures containing 15% cement replacement with fly ash and sand volume replacements with crumb rubber of 10%, 20%, 30%, 40% and 50%. Recycled concrete aggregate was included as a 50% coarse aggregate replacement by volume in two mixtures containing 20% and 30% crumb rubber content. As the crumb rubber content increased, the compressive strength, split- tensile, modulus of rupture and the modulus of elasticity decreased. The crumb rubber concrete's permeability increased within acceptable levels up to 40% replacement of sand. The results of this study determined that a 30% replacement of sand with crumb rubber (approximately 5.5% of the total mixture volume) was optimum and produced the necessary fresh and hardened properties for concrete pavement.

Raghavan *et al*. (1998) reported that mortars incorporating rubber shreds achieved workability comparable to or better than a control mortar without rubber particles. Because of the low specific gravity of rubber particles, the unit weight of the mixture containing rubber decreases with the increase in rubber content. They also observed that rubber shreds incorporated into mortar help to reduce plastic shrinkage cracking in comparison to control mortar.

Son *et al.* (2011) reported about 22% reduction in compressive strength on partial replacement of aggregates by crumb rubber. Khatib and Bayomy (1999) reported a higher reduction in case of coarse rubber particles than in case of fine rubber particles. According to Topcu (1995), the interfacial bond in a coarse tyre rubber chips and cement paste is weaker than in a fine tyre rubber chips and cement paste, which affects the compressive strength.

A study was carried out on mechanical properties, fatigue properties and damage characteristics of rubber-modified recycled aggregate concrete (RRAC) with waste rubber replacement rates of 10%, 20% and 30% for airport pavement (Feng *et al.* 2015). The flexural strength of RAC decreased by 10.2% than NC and its compressive strength increased by 10.1%. With the increase in rubber particle content in RRAC, compressive, flexural strength and elasticity modulus

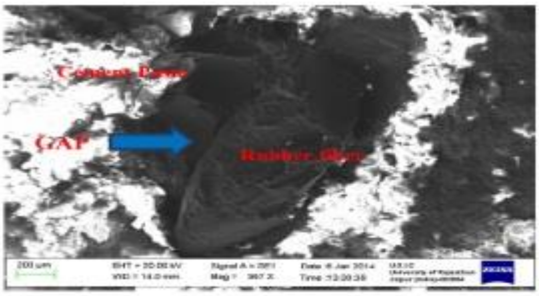

Fig. 18 Microstructure of concrete containing rubber fiber at 357x magnification (Gupta *et al*. 2016)

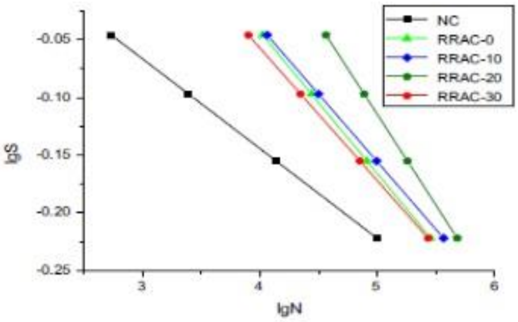

Fig. 19 Double logarithmic fatigue equation curves for the 5 types of concrete (*p*=0.2) (Feng *et al*. 2015)

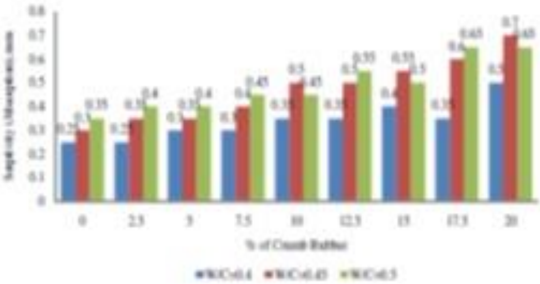

Fig. 20 Water absorption (Sorptivity) of rubberize concrete (Blessen *et al.* 2014)

Fig. 21 Abraded surface of rubberized concrete FB 38 (20% substitution) (Blessen *et al.* 2014)

decreased. With 20% of rubber particle in sand, the ultimate strain of RRAC was 3.45 times that of rubber free RAC. An analysis of the damage characteristics showed that both recycled aggregate and rubber particles could enhance the concrete's fatigue life, which was significant when the rubber particles reached 20% (Fig. 19).

An experimental investigation was made by considering copper slag and discarded rubber tyre as partial replacement for coarse and fine aggregates by Blessen *et al*. (2013). The strength and durability properties increased with increase in copper slag up to 50% replacement for sand. Due to the good durability characteristics, 15% of coarse aggregates can be replaced with rubber tyre and used in lightweight concrete. The combination of 40% copper slag and 10% tyre rubber was recommended for pavements, structural and non-structural works.

Blessen *et al*. (2014) investigated the suitability of waste tyre rubber as a partial replacement for natural river sand in cement concrete with water/cement ratios of 0.4. Compressive strength, flexural strength, abrasion resistance, micro structure, water permeability and sorptivity tests were determined. It resulted in decrease in density, decrease in compressive strength and flexural strength with increase in crumb rubber, better resistance to abrasion as shown in at 20% substitution (Fig. 21) and water permeability decreased and sorptivity increased a maximum of 0.7 mm for 20% substitution (Fig. 20).

4. Conclusions

This paper is compiled based on a thorough review of approximately more than 100 researchers work on utilization of mine waste along with some industrial waste in concrete as a replacement for aggregates. The researchers have focused on utilization of different types of mine waste for replacement for specific applications. Other materials like glass waste, plastic waste and rubber waste were also tried for replacement of fine and coarse aggregates under different conditions. However, the studies on utilization of mine waste in concrete, combination of the iron ore mine waste and tailings has not been completely explored as aggregates in concrete pavements. Hence, the utilization of these waste materials in concrete as partial replacement of fine and coarse aggregates in concrete can be done and its durability and mechanical properties can be determined in the application of concrete pavements by laboratory experimental investigations viz., compression, flexural and fatigue testing. Use of iron ore waste and tailings in concrete may improve strength, but density also increases. So, in order to reduce the density some additives like perlite and rubber can be used.

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