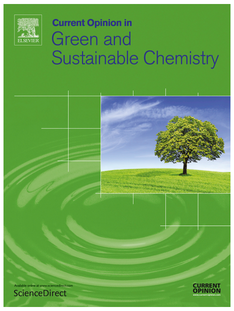

Resource efficiency impact on marble waste recycling towards sustainable green construction materials

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Resource efficiency impact on marble waste recycling towards sustainable green construction materials

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Abstract

India is one of the biggest marble producing country in the world (~10%). State of Rajasthan has nearly 85% of marble production capacity. Recently, the massive quantity of marble waste fine particulates generated in marble industry has become a major environmental hazard issue. Major minerals present in marble waste are calcite ($CaCO_3$) and dolomite ($CaMg(CO_3)_2$). The particle sizes of marble waste particulates has been found to be 200 μm (D_{90}). The chemical composition of marble wastes reveals oxides of calcium (CaO), silica (SiO_2), alumina (Al_2O_3) and alkaline oxides (Na_2O, K_2O). Apart from that, iron oxide, mica, fluorine, chlorite and organic matter have also been noticed. Marble waste has been explored for possible utilization in industries, thereby it helps in preventing the environmental problems such as dumping and pollution.

This article addresses the efficiency of marble wastes for materials development, leading to create some sustainable green composite materials for construction applications.

Introduction

The exploitation of natural resources is increasing at a very rapid speed and the problems it has caused requires immediate attention and action. To fulfill human desire, technological advancement substantially exploit the consumption of natural resources. As a consequence, there is major changes in the environmental and ecological stability, which require scientific attention to safeguard the environment and living system [1, 2]. Environmental issues associated with marble waste generation is one such example. India produces about 12 million tons of marble waste annually. For achieving sustainable development, effective marble waste material utilization is one of the most important environmental tools. Marble waste exposure to the environment can cause severe environmental problems. In particular, marble waste utilization without appropriate scientific research and study can only aggravate the environmental problems. Marble is one of the largest produced natural stone in the world and it accounts for 50% of world's natural stone production. In India, million tons of marble waste is released from marble industries during marble processing, cutting, grinding and polishing. During processing, 20-30% of marble block become dust [3]. Traditional materials like cement, concrete, composite, bricks and tiles are broadly used as a major construction materials. These construction materials consume natural resources for their production and this further causes environmental damage. Most of the building materials production processes such as lime decomposition, Calcium Carbonate and binding material cement manufacturing emit large amount of Carbon monoxide and oxides of Nitrogen and Sulphur. The release of these toxic gases into environment leads to severe air, soil and water pollution and gravely affects the human health [4]. Carbon dioxide emissions from such materials can be controlled by replacing cement or proportion of cement with a waste material such as marble waste that potentially improves the specification [5-7].

This paper provides a detailed literature on marble waste utilization in different construction materials (bricks, cement, composites, and concrete). Based on the existing studies, a comparative graph between the different mechanical and physical properties of marble waste based construction materials has been plotted and discussed. The review also concludes the finding of the study.

Use of marble waste concrete in concrete

Construction material such as concrete has been prepared by mixing coarse aggregate, fine aggregate and binding material (cement) with water. Concrete production contributes to CO_2 emission which pollutes the environment. For reducing CO_2 emission from concrete, cement can be replaced by industrial waste marble dust. Many researchers have studied the production of concrete with marble waste and its mechanical performance with varying percentage of marble waste content. The performance of marble waste concrete with varying marble waste content reported by various researchers have been analyzed and summarized below (Table 1, Figure 1, 2, 3, and 4).

Alyamac and Ince 2009 [3] have studied the concrete mix design for self-compacting concrete with marble powder. For this purpose, different mixes with water/marble powder ratios and water/cement ratios were prepared. Various tests like T_{500} time, slump cone, V-funnel, sieve segregation resistance and L-box were performed for fresh concrete and tests such as split – tension strength and compressive strength were applied to hardened concrete. The results showed a compressive strength of 34.5- 64.5 MPa (Table 1) at curing of 28 days in a moist room at about 23 C temperature. The study emphasizes that marble waste material can be economically and successfully utilized as supplementary filler material in self- compacting concrete technology.

Binci et al., 2008 [5] studied the use of granite and marble waste as recycled aggregate in concrete, using marble waste as a coarse aggregate and river sand and blast furnace slag as a fine aggregate. Their test result showed compressive strength of 29.2 – 44.3 MPa, flexural strength of 6.4 MPa and tensile strength of 3.3 MPa (Table 1). The authors concluded that granite and marble aggregate can be used for better workability, improving chemical resistance and mechanical properties of the conventional concrete mixture.

Sardinha et al., 2016 [6] studied the properties of concrete using very fine aggregates of marble sludge. The concrete sample has been prepared using cement, dry marble sludge, aggregate, and superplasticizers. The test result shows a compressive strength of 39.2 - 53.6 MPa. This research also demonstrated that as cement and marble sludge content increases in concrete, the durability characteristics of concrete get worse.

Topcu et al., 2009 [8] studied the effect of marble dust waste content as filler on the properties of self-compacting concrete. The concrete samples have been prepared using cement, coarse aggregate, sand, marble dust and superplasticizer. Various test were performed on fresh concrete (L-box test, V-funnel test, and slump-flow) and on hardened concrete (compressive strength and flexural strength). The results showed compressive and flexural strength of 59 MPa and 11 MPa respectively. It was also observed that the mechanical strength of hardened concrete decreased by using marble dust at 200 kg/m^3 content.

In another work, effect of marble sludge waste on the different properties of concrete paving blocks was studied by Mashaly et al., 2015 [9], where concrete samples were prepared using cement (210 – 315 kg/m^3), marble sludge (35 – 140 kg/m^3), fine aggregate (660 – 695 kg/m^3) and coarse aggregate (1140 – 1175 kg/m^3). Both cement and marble sludge were mixed with optimum water content (W/C 0.48 – 0.91).The concrete mixture was then molded to produce concrete units with dimensions of 200 x 100 x 60 mm and packed by a mechanical vibrator. After demold from the mold in 24 hours, the concrete samples were cured using a plastic sheet. Test results showed marble sludge could be used to improve the properties of conventional concrete paving block, with a compressive strength of 26.42 – 36.60 MPa, 7.8 – 9.9% water absorption and approx. 2.12 – 2.15 g/cm^3 density of concrete.

Effect of diatomite and waste marble powder on the mechanical properties of concrete have been reported by Ergun, 2011 [10]. Concrete samples were prepared using cement (270-285 kg/m^3), waste marble powder (15-30 kg/m^3), super-plasticizer (3 kg/m^3), river sand (312.3 kg/m^3) and crushed stone (507.7-565 kg/m^3), with water/binder ratio of 0.50. The concrete sample was casted in cubes (100 x 100 x 100 mm) and beams (100 x 100 x 300 mm) molds. The samples were removed from the mold after 24 hours followed by curing in lime-saturated water at 20 °C. These samples showed a compressive strength of 31.1-39.4 MPa and flexural strength of 5.0-5.3 MPa. It was also observed that the concrete samples containing 5% waste marble powder as a partial replacement for cement exhibited a higher compressive strength than control concrete specimen.

The effect of waste physicochemical treatment sludge of travertine waste water on the properties of concrete was studied by Sogancioglu et al., 2015 [11]. The concrete sample were prepared using cementitious material (cement), coarse aggregate, fine aggregate, water and admixture of alum sludge, nonionic flocculant sludge and sodium aluminate sludge. Concrete was molded in cubic molds of 150 x 150 x 150 mm and after demolding samples were placed for curing in water at 25 °C. Test results showed significant compressive strength (21-29 MPa), water absorption (2.6-3.59 %) and density (2.16-2.28 g/cm^3). It was also found that utilization of treated travertine sludge as an admixture in concrete imparts strength up to 12-15%.

“Impact of marble waste (coarse aggregate) on different properties of lean cement concrete was studied by Kore and Vyas 2016 [12]”. In this study, the conventional coarse aggregate was replaced by marble aggregate in different proportions. Concrete samples were prepared using cement (310 kg/m^3), sand (646.87 kg/m^3), natural coarse aggregate (0-1170.85 kg/m^3), marble coarse aggregate (0-1170.85 kg/m^3) and water (191.91 lit/m^3). The concrete mix were filled in molds in three layers and each layer was compacted on vibrating table as per Indian standard (BIS: 516-1959). The test result showed the compressive strength of 15.98-19.95 MPa.

Incorporation of marble waste as a filler in self- compacting concrete was studied by Tennich et al., 2015 [13]. The concrete were prepared using cement (350 kg/m3), gravel (794.8-824.6 kg/m^3), sand (786-815 kg/m^3), marble waste (100-200 kg/m^3) and superplasticizer (1%). Concrete specimens were kept in casting the molds for 24 hours and then cured in water at 20 □C. The specimen showed the compressive strength of 35.5 MPa. It was observed that the addition of marble waste filler in self-compacting concrete increases its compressive strength by about 6.7%.

Influence of limestone waste and marble powder as a partial replacement for fine aggregate was studied by Omar et al., 2012 [14]. Concrete samples were prepared using cement (350-450 kg/m^3), limestone waste (25-75%) and marble powder (5-15%). The mix were designed to have fixed water-cement ratio of 0.47 and a constant slump in the range of 90-110 mm. Test results showed compressive strength of 35.2-40.6 MPa, flexural strength of 6.2 MPa and tensile strength of 4.1 MPa. It was found that limestone waste replacement by 50% increases the compressive strength about 12% at 28 days.

Marble powder incorporation in high-performance concrete were studied by Talah et al., 2015 [15]. Concrete samples were prepared of cement (340 kg/m^3), marble powder (60 kg/m^3), sand (788 kg/m^3), gravel (1049 kg/m^3) and water (200 kg/m^3). These sample were compared with reference concrete (without marble powder). The strength values for high-performance marble powder concrete ranged from 49 to 65 MPa and for reference concrete ranged from 26 MPa to 48 MPa. The result indicated a definite improvement in compressive strength with marble powder.

Vardhan et al., [16] studied the use of marble powder in cement mortar as a partial replacement of cement. The study was conducted on cement mortar prepared with and without marble powder and the results were compared with control mix mortar sample (without marble powder). It was observed that mortar sample consisting of 20% marble powder attained compressive strength of 41.67 MPa (Table 1) comparable to that control mix mortar sample.

Detailed study on mechanical properties of concrete containing fine aggregate from marble cutting sludge has been done by Rodrigues et al., 2015 [17]. The research evaluated the mechanical properties of concrete with the addition of marble sludge waste as cement replacement (0%, 5%, 10% and 20%) with plasticizers. It was observed that as the replacement ratio increased, compressive strength decreased. Although the insignificant reduction in strength up to replacement ratios of 10%. However, the plasticizers improved the compressive strength of concrete due to water/cement ratio reduction.

Effect of marble waste on properties of concrete paver blocks has been studied by Gencel et al., 2011 [18]. For this purpose, aggregate were partly replaced with waste marble. Paving blocks sample was prepared using cement (400 kg/m^3), marble waste (0-40 %), fine aggregate (505-907 kg/m^3), coarse aggregate (509-913 kg/m^3) and water (192-240 kg/m^3). The samples were cured at 20 °C and a relative humidity of 65%. The samples demonstrated a compressive strength of 30 MPa (approx.), water absorption of 5.25% (approx.) and tensile strength of 3.7 MPa (approx.). It was concluded that waste marble in the concrete paving block is well applicable instead of aggregate.

The feasibility of utilizing marble waste in concrete was investigated by Aliabdo et al., 2014 [19]. This research investigated the properties of concrete contained cement as a sand replacement. The concrete samples were prepared using cement (340-400 kg/m^3), marble dust (0-15 %), sand (581-726 kg/m^3), coarse aggregate (1021-1028 kg/m^3) and water (160-200 kg/m^3). Test results showed compressive strength of 34.5-53 MPa and tensile strength of 3.7-4.5 MPa. It was noted that marble dust modified mortar had 5% lower compressive strength than that of control sample (15% marble dust).

Sadek et al., 2016 [20] studied utilization of marble and granite powder as a mineral additive in self-compacting concrete. The samples were prepared using cement (400 kg/m^3), silica fume (40 kg/m^3), marble powder (160-200 kg/m^3), granite powder (160-200 kg/m^3), coarse aggregate (797-200 kg/m^3), fine aggregate (797-200 kg/m^3), water (180 kg/m^3) and polycarboxylate-based superplasticizer (7.95 kg/m^3). After demoulding, samples were cured in water tank at 20 °C. Test results showed compressive strength of 39 MPa, 3.84% water absorption, flexural strength of 9 MPa (approx.) and tensile strength of 3 MPa (approx.). It was also found that compressive strength of the samples was increased by 1.7, 3.9 and 9.5% with 30, 40 and 50% marble powder content respectively.

Applicability of marble and granite powder residual as a cement replacement at variable water-cement ratios in concrete studied by Bacarji et al., 2013 [21]. Concrete samples were prepared of marble granite residue (0-20%), cement (277-450 kg/m^3), fine aggregate (699.3-770.7 kg/m^3), and coarse aggregate (937.9-953.5 kg/m^3) with effective water to cement ratios of 0.50 and 0.65. After casting, the specimens were moved to a moist chamber, with 75% relative humidity at 21 °C temperature. The specimens showed the compressive strength of 15.5-31.5 MPa and 6-7.8% water absorption.

Hebhoub et al., 2011 [22] studied the utilization of waste marble as natural aggregates replacement in concrete. The concrete samples were manufactured at a constant water to cement ratio (0.5) using crushed natural gravel, wastes of a white marble quarry, natural sand and cement (350 kg/m^3). The natural aggregate was substituted by recycled aggregate (marble waste) at 25%, 50%, 75% and 100% proportion. The samples showed the compressive strength of 20-33 MPa (approx.), 2.45-2.47% (approx.) water absorption and tensile strength of 2.5-3.8 MPa (approx.).The authors reported that substitution of natural aggregate by marble waste aggregate is beneficial up to 75% for concrete resistance and at 75% gravel substitution the compressive strength gain of concrete was 25.08%.

Marble waste utilization in making bricks

Traditionally, bricks are prepared using nonrenewable resource; soil, fired at high temperature. As the building requirement increases day by day, requirement of bricks has increased exponentially. Due to non-availability of suitable soil, there is an urgent need for alternative suitable raw material to manufacture bricks via an energy-efficient pathway. Many researchers have focused on bricks production using marble waste and studied mechanical performance with varying percentage of marble waste content. The performance of marble waste bricks with varying marble waste content reported by various researchers have been analyzed and summarized below (Table 2, Figure 5, 6, 7).

Utilization of granite and marble sawing waste in formation of industrial bricks was studied by Dhanapandian and Gnanavel, 2009 [23]. Bricks sample were prepared with 0, 10, 20, 30, 40 and 50 wt. % of waste content into raw clay and then fired at 500-900 °C. The test samples exhibited a compressive strength of 19.82 MPa, 11-21% (approx.) water absorption, density of 1.51-1.68 g/cm^3 and flexural strength of 30.61 MPa. It was observed that incorporation up to

10% of marble waste into raw clay decreases the strength of bricks and increases its water absorption. In theirnext work [24], the authors investigated the effect of incorporation of marble and granite wastes on the production of clay bricks. Bricks sample were prepared using clay, dry marble, and granite powder wastes (0-50%). The samples were sintered at a temperature between 500 to 900 °C for 2 hours. Test samples showed, 15.81-17.21% water absorption and density of 1.914-2.043 g/cm^3. It was observed that increase in the value of the bulk density of bricks at different wt. % content of waste indicates the fusion of marble and granite powder in the pores of clay.

Characteristics of building material fired clay bricks with the addition of waste marble powder have was studied by Sutcu et al., 2015 [25]. Bricks sample were prepared using clay (65-95%), marble waste (5-35%) and water (about 15%) and were compressed using a hydraulic press with a pressure of 40 MPa and sintered at 950 and 1050 °C. The samples showed compressive strength of 6.2-34.2 MPa, 10.9-26.9% water absorption and density of 1.59-2.05 g/cm^3. Bricks with 30% marble waste fired at 950 °C and 1050 °C exhibited sufficient compressive strength from 8.2 to 32.1 MPa.

Marble sludge incorporation in production of eco-blocks or cement bricks was studied by Aukour 2009 [26]. Samples were prepared using air-dried sludge, limestone gravel, and black cement. After drying samples were soaked in water for curing. The samples showed 7.8 MPa compressive strength after 28 days and 7% water absorption. The author concluded that the results of prepared block samples satisfied the Jordanian standard, the so- manufactured samples shows better properties as compared to commercial building blocks.

Production and manufacturing of lightweight bricks from sawdust, marble, spent earth from filtration were studied by Eliche-Quesada et al. 2012 [27]. The samples were prepared using sawdust (0-10%), marble (0-20%), spent earth from oil filtration (0-30%) as raw materials and were fired at 950 and 1050 °C. The results showed that maximum strength for the samples that were sintered at 1050 °C, whereas the samples fired at 950 °C had open porosity, leading to decreased compressive strength of bricks. It was also found that the optimum amount of waste was 5% sawdust, 10% compost, and 15% marble and spent earth from oil filtration.

Gnanavel et al. 2009 [28] investigated the utilization of granite and marble sawing powder wastes in the formulation of building bricks. The samples were prepared with workable consistency by mixing marble and granite waste with raw clay (0-50%) using a planetary mill. The prepared specimens were then sintered 500 to 900 □C for 2 hours. Test results showed compressive strength of 0.6- 1.2 MPa, 12.5- 22% water absorption, density of 1.79- 1.93 g/cm^3 and flexural strength of 0.1- 0.6 MPa. The authors observed that the addition of marble and granite waste in clay bricks has a negligible effect on properties of prepared bricks.

Hamza et al. 2011 [29] reported the utilization of different sizes of marble and granite waste in concrete bricks. In samples preparation, conventional sand and aggregate were replaced by granite and marble wastes of different sizes. The prepared samples were tested for compression strength after 7 and 28 days water curing. It was found that 10% granite slurry incorporation put a positive effect on compressive strength of prepared brick samples.

Munir et al. 2017 [30] reported the incorporation of waste marble sludge in fired clay bricks. The samples were prepared with different dosages (5- 25%) of marble slurry that were manually mixed with clay. Freshly prepared wet samples were sun-dried for 3 days and then fired in a kiln at approximately 800 ºC for 36 hours and were removed from the kiln after 45 days. It was observed that up to 15% marble slurry incorporation satisfied the minimum compressive strength requirement. Beyond 15% marble slurry, the compressive strength was observed to be decreasing.

Use of marble waste for making polymeric composite materials

Many researchers have studied the production of composites with marble waste, and their mechanical performance with varying percentage of marble waste content. The performance of marble waste composites with varying marble waste content reported by various researchers have been analyzed and summarized below (Table 3, Figure 8).

Characterization of glass fiber reinforced composite tiles fabricated from poly (ethylene terephthalate) and micro marble particles was studied by Icduygu et al., 2012 [31]. In the fabrication of polyester composite tiles, micro marble particles were used as a filler. Three different particles size distributions were used (32 μm, 90 μm and 200 μm). Adipic acid, maleic anhydride, methyl ethyl ketone peroxide, styrene, propylene glycol, cobalt naphthalate, methylene chloride, sodium hydroxide and zinc acetate were used for polyester resin preparation. The mixture was initially heated at 80 °C for 1 hour then temperature increased to 210 °C at a rate of 10 °C/hour. The mold was placed in an already heated press with a force of 44.4 KN. Test results showed a flexural strength of 32.9-42 MPa and flexural stiffness of 8.9 GPa. Significant improvements were observed in the tiles prepared with coarse grade marble, with flexural stiffness, flexural strength, and strain at failure were achieved up to 94.6 MPa, 138.9 MPa and 62.8% respectively.

Borsellino et al., 2009 [32] studied the performance of composite reinforced with marble powder and effect on properties due to the different matrix (polyester and epoxy resins) and filler amount (60, 70, and 80 %). Panels were made in a wooden mold after homogenous mixing of resin/powder. The mold was in the rotation to avoid marble deposits on specimen side until curing of matrix occurs. Marble composites with epoxy resin showed strain of 0.005-0.007 %, young's modulus of 4861-8145 MPa and maximum stress of 22.2-10.6 MPa. On the other hand, marble composite with polyester resin showed strain (0.0025-0.0054%), young’s modulus (7333-9079 MPa) and maximum stress (30.7-16.6 MPa).

Utilization of marble processing waste in epoxy resin composite has been studied by Ahmetli et al., 2012 [33]. Marble processing waste (20%) and epoxy resin were mixed (30 minutes) and then poly epoxy hardener (30%) was added. The mixture was degassed at 40 °C for 60 minutes and then transferred into a mold. The samples were cured in an oven at 60 °C to 120 °C for 24 hours. The sample showed strain of 0.582-0.959 %, Young’s modulus of 18.571-17.667 MPa and tensile strength of 5.52-5.83 MPa. It was noted that marble processing waste-pumice reinforced composite exhibited nearly 10% increment in elastic modulus. On the other hand, the marble processing waste-sepiolite or zeolite reinforced composite showed an impressive 76.67-143.33% increase in elastic modulus as compared to pure epoxy matrix.

Ahmed et al., 2014 [34] investigated the development of natural rubber hybrid composite prepared using marble sludge and rice husk derived silica as reinforcement. The rubber was compounded on a two- roll mill. The rubber compound was moved through tight nip gap and then sheeted out. The compounded rubber was subsequently cured in a compression molding machine at 170 °C for 20 minutes. The test results showed that marble sludge derived silica hybrid composites showed superior properties as compared to rice husk derived silica composites.

Ahmed et al. 2013 [35] have studied the natural rubber hybrid composite that were prepared by adding marble sludge silica at various weight ratios. For sample preparation, two roll mill compounding was carried out with 60 parts per 100 rubber total filler loading. Composite samples were vulcanized at 140 □C. Prepared samples test results showed Young's modulus of 0.73- 2.04 MPa and tensile strength of 5.08- 23.12 MPa. The authors concluded that marble sludge from marble processing industry could be used as a filler in natural rubber compounds.

Use of marble waste for miscellaneous applications

Incorporation of marble residue and sewage sludge as a substitution of clay raw material in the manufacturing of ceramic tile has been studied by Montero et al., 2009 [36]. Samples were prepared using ceramic clay, marble sludge (1, 2, 3, 4, 5 and 10%) and marble residue (15, 20, 25, 30 and 35 pressed at a pressure of 40 MPa followed by 1050 □C. The samples showed bending strength of 1.09-2.05 MPa. The authors noted that bending strength decreased with increase in sludge content.

Utilization of marble sludge waste as a major raw material in calcium sulfoaluminate-belite cement was studied by El-Alfi and Gado, 2016 [37]. They investigated the influence of raw mix composition at different burning temperature. Samples were prepared using kaolin (15-25%), gypsum (20%) and marble sludge waste (55-65%). Thick paste was made with chemical oxides using a low amount of water (5% approx.) and was then molded under a pressure (50 MPa), followed by drying and firing at (1150-1250 □C). The test samples showed bulk density of 1.80-1.90 g/cm3, apparent porosity of 14.85-24.53% and compressive strength of 9.86-36 MPa. It was found that the sample prepared at 1250 □C gives the best burn ability as well as a good strength due to hydration process with maximum sulfoaluminate-belite phases.

Use of marble dust in red tropical soil as a stabilizing additive has been studied by Okagbue and Onyeobi, 1999 [38]. A marble dust was added in varying proportions (0-10 %) for the determination of geotechnical properties of red tropical soil. Results showed that marble dust addition reduced the plasticity by 20-33%, increased the strength by 30-46% and increased California bearing ratio value by 27-55%. It was found that higher unconfined compressive strength (560 MPa) and California bearing ratio (42.5 MPa) were achieved at 8% marble dust content. The authors also observed that after 7 to 10 days of normal curing, 80% strength gain was achieved in marble dust-treated soil.

Environmental issue associated with marble waste disposal

Marble manufacturing involves cutting, polishing and finishing process to obtain marble from quarries. During these processes about 25% of original marble mass is lost in the forms of waste as marble dust and marble sludge [39]. This marble waste is dumped in open lands, which gets suspended in the atmospheric air with time and is inhaled by humans and animals. Studies indicate that humans exposed to marble waste particles have an increased risk of suffering from chronic bronchitis, asthma symptoms, impairment of lung functions and nasal inflammation. Marble waste dust particles spread over nearby agricultural fields and reservoirs affects the water, aquatic life, soil, vegetables and other natural resources. In present era, society is based on linear economic model of extract-process-consume-dispose [40-43]. In India, 1931 mega tons of natural marble resources is still left to be exploited [44]. Hence, there is an urgent need for holistic management approach for marble waste: From waste to wealth through green chemistry.

Conclusions

The environmental impact of marble wastes recycling towards sustainable construction materials has great practical significance. In India about 12 million tons of marble wastes is released annually. This value is relatively lower than that of major marble producers such as Italy, the world leader in marble waste production (~20%) followed by China (~16%). India is the third largest producer of marble (~10%) in the world. Considerable research has been done in past decade for recycling marble wastes, by utilization in making building and construction materials. The highlights of the technical significance of marble wastes based building materials are summarized below:

- The 28th day compressive strength of bricks showed 65 MPa at 60 kg/m^3 marble waste and 100 kg/m^3 cement content.
- The maximum compressive strength (47.3 MPa) of ceramic brick fired at 1050 □C was achieved at 20% marble waste incorporation.

- The lowest water absorption (7%) was found in marble sludge eco-blocks at 20% marble waste content along with a compressive strength of 7.8 MPa.
- The highest tensile strength of natural rubber composite was 21.75 MPa at 10% marble waste content.
- Marble processing waste-pumice reinforced epoxy composite showed about 10% increased elastic modulus over the pure epoxy matrix.
- Marble processing waste - sepiolite reinforced composite resulted in 76 -143% increased in elastic modulus as compared to pure epoxy matrix.

Mismanagement of marble wastes create major environmental and ecological problem as it contaminates soil, ground water and dissipate air pollution and thus affect human health. There is a tremendous scope for further research for recycling and making sustainable green materials, from marble waste that will create further employment, provide income to rural and urban mass while arresting further pollution of the environment.

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Table 1. Impact of marble waste on different properties of concrete

No.	Concrete type	Raw material	Marble waste content	Curing condition	CS (MPa)	WA (%)	D (g/cm^3)	FS (MPa)	TS (MPa)	Reference
1	Self compacting concrete	Aggregate, cement sand, viscocrete, marble powder	0- 450 kg/m^3	C- 28 days in moist room at about 23°C temp.	34 -64.5	-	-	-	-	Alyamac and Ince, 2009
2	Marble concrete	Cement, super plasticizers, aggregates, river sand	740 – 1180 kg/m^3	C- moist curing room at 22°C.	29.2-44.3	-	2.35	6.4	3.3	Binici et al., 2008
3	Fine aggregate marble sludge concrete	Cement, dry marble sludge, aggregate, super plasticizers	5 – 20%	-	39.2-53.6	-	-	-	-	Sardinha et al., 2016
4	Self compacting concrete	Cement, coarse aggregate, sand, marble dust, super plasticizer	0- 300 kg/m^3	C- cured in water for 28 days.	59	-	-	11	-	Topcu et al., 2009
5	Concrete paving block	Cement, aggregates, marble sludge	0- 40%	C- cured for 28 days.	26.42-36.60	7.8-9.9	2.12-2.15 approx.	2.41-4.38	-	Mashaly et al., 2015
6	Waste marble powder concrete	Cement, aggregate, sand, super plasticizer, marble powder	5- 10%	C- cured in lime saturated water at 20 °C.	31.1-39.4	-	-	5.0-5.3	-	Ergun, 2011

7	Travertine processing wastewater concrete	Cement, coarse aggregate, fine aggregate, travertine marble processing wastewater	5- 15%	C- cured in lime water at 25 □C.	21-29	2.6-3.59	2.16-2.28	-	-	Soganciogl u et al., 2015
8	Lean cement concrete	Cement, fine aggregate, coarse aggregate, marble aggregate	20- 100%	C- cured in water at room temp.	15.98-19.95	-	-	-	-	Kore and Vyas, 2016
9	Self compacting concrete	Cement, gravel, sand, limestone filler, marble waste	50- 200 kg/m^3	C- cured in water at 20 □C.	35.5 approx.	-	-	-	3.56	Tennich et al., 2015
10	Marble powder concrete	Cement, sand, crushed stone, marble powder, limestone waste	5- 15%	C- cured in water tank at 25 □C.	35.2-40.6	-	-	6.2	4.1	Omar et al., 2012
11	High performanc e concrete	Cement, marble powder, aggregate	60 kg/m^3	C- cured in water.	49-65	-	-	-	-	Talah et al., 2015
12	Marble powder mortar	Cement, marble powder waste, sand	10- 50%	C- water cured at 27 □C.	41.67	-	-	-	-	Vardhan et al., 2015
13	Marble sludge concrete	Natural aggregates, gravel, cement,	0- 20%	-	28-37.3	-	2.30-2.34	-	2.4-3.1	Rodrigues et al., 2015

		plasticizer								
14	Concrete paving blocks	Cement, aggregates, crused waste marble	10- 40%	C- cured at 20 □C temp.	30 approx.	5.25 approx.	-	-	3.7 approx.	Gencel et al., 2012
15	Marble dust concrete	Cement, fine aggregate, coarse aggregate, marble dust	0- 15%	C- water curing.	34.5-53 approx.	-	-	-	3.7-4.5 approx.	Aliabdo et al., 2014
16	Self compacting concrete	Cement, fine aggregate, coarse aggregate, marble powder, super plasticizer	10- 50%	C- water curing at 20 □C.	39	3.84	-	9 approx.	3 approx.	Sadek et al., 2016
17	Marble residue concrete	Cement, marble residue, granite residue, aggregates	0- 20%	C- moist chamber at 21 □C temp.	15.5-31.5 approx.	6-7.8 approx.	-	-	-	Bacarji et al., 2013
18	Marble aggregate concrete	Cement, natural sand, gravel, natural aggregates	25- 100%	C- 28 days.	20-33 approx.	2.45 - 2.47 approx.	-	-	2.5-3.8 approx.	Hebhoub et al., 2011

CS: compressive strength; D: Density; WA: Water Absorption; FS: Flexural Strength; TS: Tensile strength.

Table 2. Impact of marble waste on different properties of bricks

No.	Brick type	Raw material	Marble waste content	Curing condition	CS (MPa)	WA (%)	D (g/cm^3)	FS (MPa)	Reference
1.	Marble sawing powder brick	Clay, dry granite and marble sawing powder	0- 50%	F- 500 to 900 °C for 2 hr.	19.82	21 – 11 approx.	1.51 – 1.68 approx.	30.61	Dhanapandian and Gnanavel, 2009
2.	Marble waste brick	Clay, dry granite and marble sawing powder	0- 50%	F- 500 to 900 °C for 2 hr.	-	17.21 – 15.81	2.043 – 1.914	-	Dhanapandian and Gnanavel, 2009
3.	Marble powder clay bricks	Clay, marble powder	0- 35%	F- 600 – 1050 °C for 2 hr.	34.2 – 6.2	26.9 – 10.9	2.05 – 1.59	-	Sutcu et al., 2015
4.	Marble sludge Eco-blocks	Marble sludge, limestone gravel, cement	0- 25%	-	7.8	7	-	-	Aukour, 2009
5.	Marble residue bricks	Clay, marble residue	0- 20%	F- 950 to 1050 °C for 4 hr.	47.3	-	1.69	-	Eliche-Quesda et al., 2012
6.	Marble sawing powder brick	Clay, granite and marble sawing powder	0- 50%	F – 500 to 900 °C for 2 hour	1.2 – 0.6 approx.	22 - 12.5 approx.	1.79 – 1.93 approx.	0.6 – 0.1 approx.	Dhanapandian et al., 2009
7.	Marble waste concrete bricks	Marble and granite slurry powder, cement	0- 40%	-	39.4	-	-	-	Hamza et al., 2011
8.	Fired clay bricks	Clay, waste marble sludge	5- 25%	F- 800 °C for 36 hours	4.5 – 8 approx.	17 – 23 approx.	-	-	Munir et al., 2017

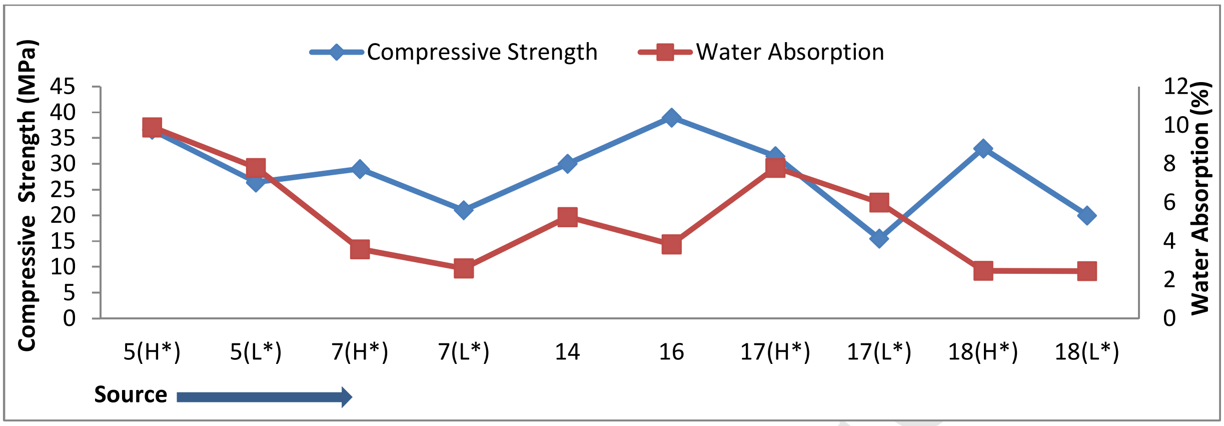
CS: compressive strength; D: Density; WA: Water Absorption; FS: Flexural Strength.

Table 3. Impact of marble waste on different properties of composite

No.	**Composite**	**Marble waste content**	**FS (MPa)**	**F STF (GPa)**	**S (%)**	**YM (MPa)**	**MS (MPa)**	**TS (MPa)**	**Reference**
1.	Composite tile	77%	32.9 – 42	8.9	0.5 %	-	-	-	Icduygu et al., 2012
2.	Marble composite (Epoxy)	60- 80%	-	-	0.007 – 0.005	4861-8145	22.2 – 10.6	-	Borsellino et al., 2009
3.	Marble composite (Polyester)	60- 80%	-	-	0.0054 – 0.0025	7333-9079	30.7 – 16.6	-	Borsellino et al., 2009
4.	Epoxy resin composite	20%	-	-	0.582-0.959	18.571 – 17.667	-	5.52 – 5.83	Ahmetli et al., 2012
5.	Natural rubber hybrid composite	0- 60%	-	-	-	1.78	-	6.50	Ahmed et al., 2014
6.	Natural rubber composite	0- 60%	-	-	-	0.73-2.04	-	5.08-21.75	Ahmed et al., 2013

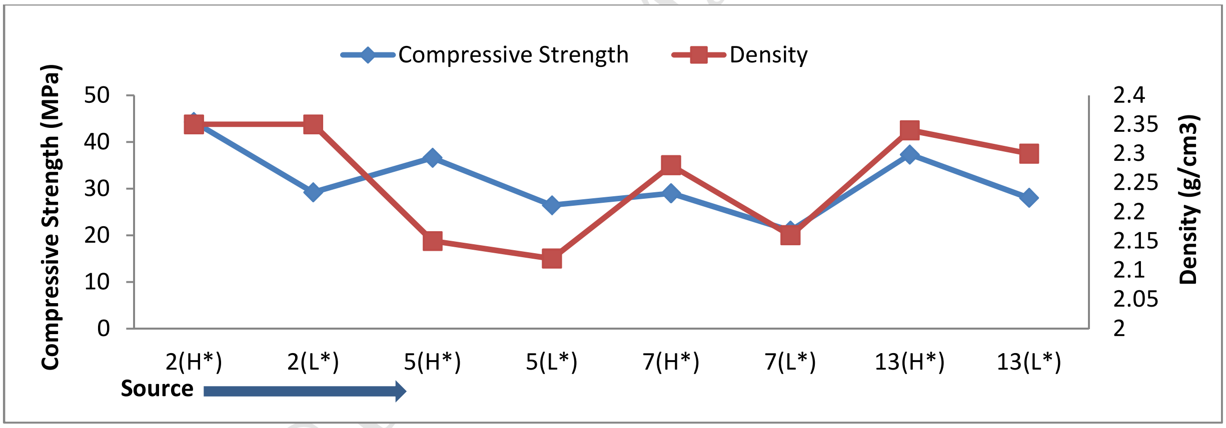
FS: Flexural Strength; FSTF: Flexural Stiffness; S: Strain; YM: Young’s Modulus; MS: Maximum Stress; TS: Tensile Strength.

Figure 1



Compressive strength and water absorption of concrete made using marble waste (*H: Highest compressive strength; *L: Lowest compressive strength).

Figure 2



Compressive strength and density of concrete made using marble waste (*H: Highest compressive strength; *L: Lowest compressive strength).

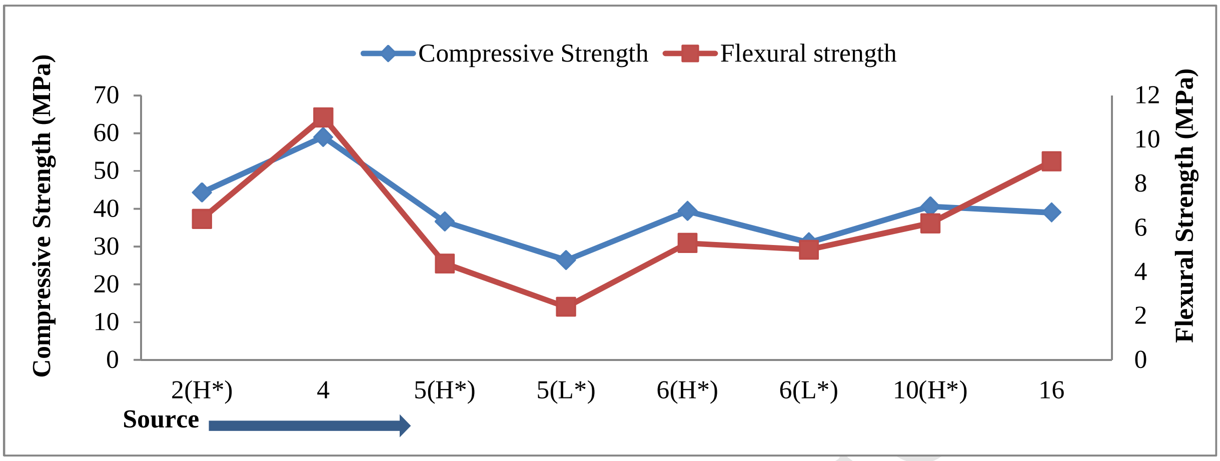
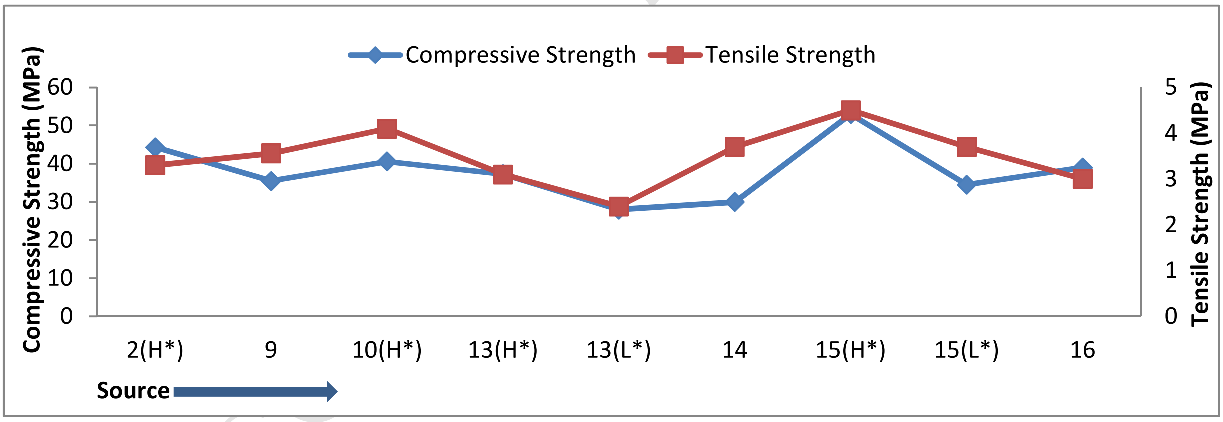


Figure 3

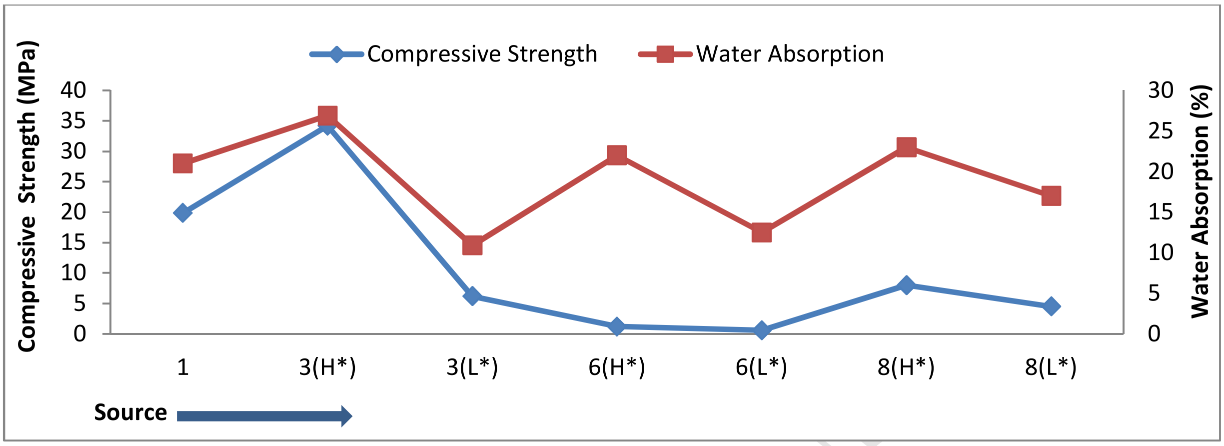
Compressive strength and flexural strength of concrete made using marble waste (*H: Highest compressive strength; *L: Lowest compressive strength).

Figure 4



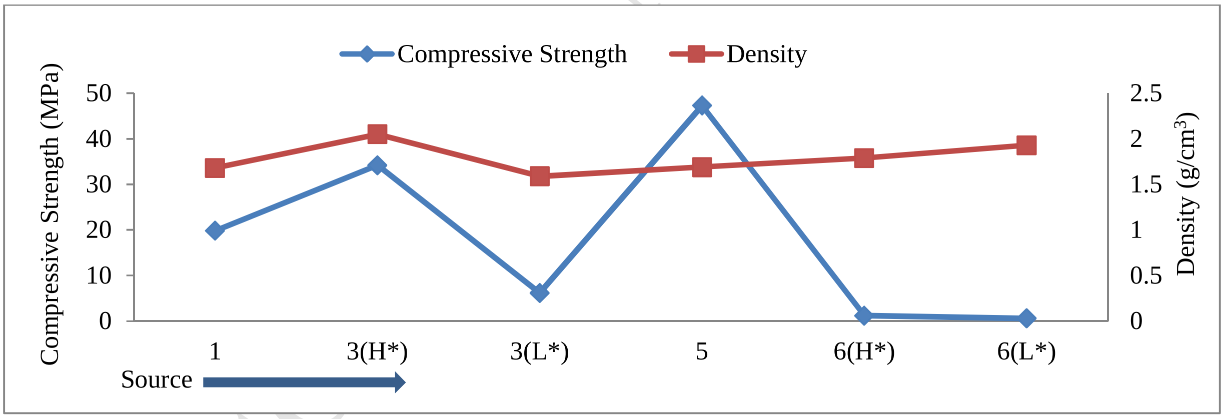
Compressive strength and tensile strength of concrete made using marble waste (*H: Highest compressive strength; *L: Lowest compressive strength).

Figure 5



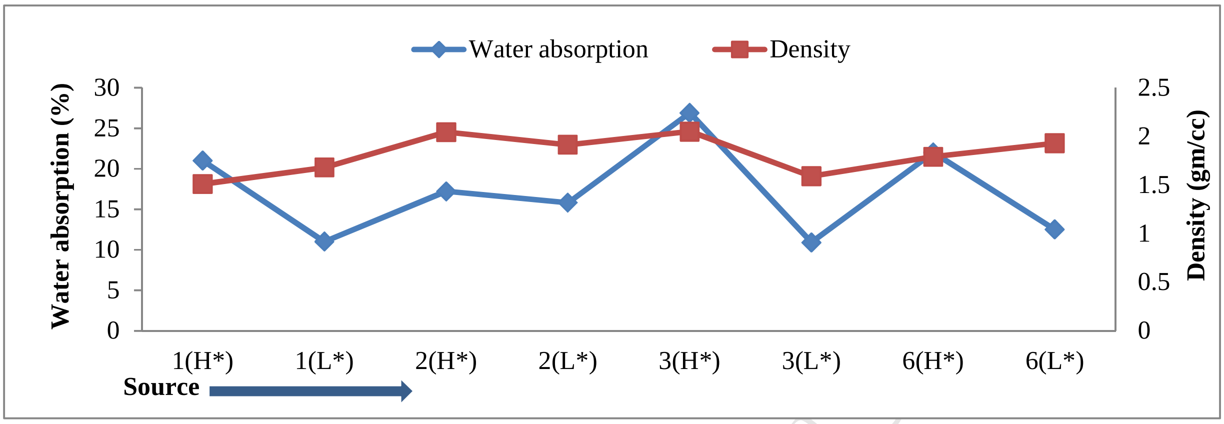
Compressive strength and water absorption of bricks made using marble waste (*H: Highest compressive strength; *L: Lowest compressive strength).

Figure 6



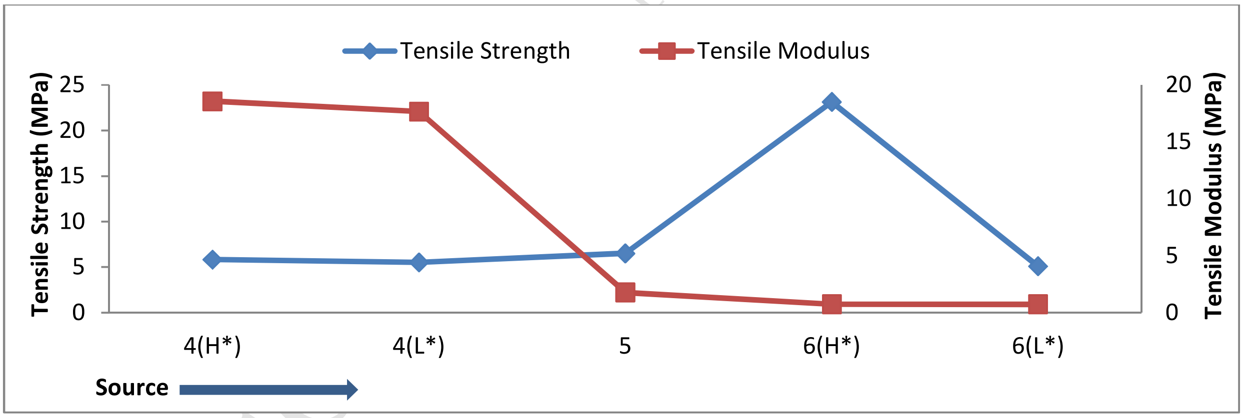
Compressive strength and density of bricks made using marble waste (*H: Highest compressive strength; *L: Lowest compressive strength).

Figure 7



Water absorption and density of bricks made using marble waste (*H: Highest water absorption; *L: Lowest water absorption).

Figure 8



Tensile strength and tensile modulus of composite made using marble waste (*H: Highest tensile strength; *L: Lowest tensile strength).