



## Utilization of E-waste & Marble Waste Slurry in Production of Tuff Tile for Sustainable Environment

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### ABSTRACT

E-waste and the waste slurry from marble are now a significant environmental and disposal concern everywhere. It reviews the process of producing tuff tiles using recycled waste materials which are important for the construction industry. The intention of the project is to cut down pollution by replacing common ingredients in tiles—fine aggregates and cement—with marble slurry and e-waste plastics, but still keep the structure and function of the tiles. All main factors such as compressive strength, flexural strength, water absorption, abrasion resistance, density, thermal conductivity and the carbon footprint reduction are analyzed through a meta-analysis of experimental evidence. It was found that mixing up to 10% e-waste with 25% marble slurry brings the best results. Discarded electronics reduce the weight of tiles and enhance thermal comfort and marble slurry increases the strength and smoothness of tiles due to having fine particles and fillers. The main environmental gain is a 30% drop in CO<sub>2</sub> emissions, mainly because of the replacement of cement and natural aggregates. Using industrial waste lessens manufacturing costs and supports a circular economy. From the research it is evident that using both e-waste and marble slurry in tuff tile making is technically possible, supports sustainability and is good for business. It shows the potential for more waste materials to be used in construction, encouraging new sustainable construction ideas. More studies should be done in the areas of field use, long-term performance checks and standardized ways to design concrete mixes. Creating tuff tiles from these wastes lessens major environmental issues and also promotes sustainability and waste management around the world.

## **Introduction**

Industrial and technological progress in recent years has resulted in growing challenges like the collection of electronic trash (e-waste) and the contamination caused by marble waste slurry created by construction and mining. Having a lot of volume, lasting in the environment and being hazardous, these types of waste cause serious challenges to environmental sustainability. Since people want businesses to become more sustainable, new waste management approaches are appearing to change leftover products into useful resources. These wastes can be used to make tuff tiles which are both strong and attractive and these tiles serve as paving in sidewalks, driveways, patios and roads. As well as dealing with environmental issues caused by dumping, this new method helps conserve the natural materials usually made into tiles (Palaniveloo et al., 2020).

E-waste such as computers, mobile phones, televisions and other electronic devices, is one of the fastest growing types of waste everywhere. According to the Global E-waste Monitor, there were 53.6 million metric tons of e-waste in 2019 and the report also predicts a rise in the years to come. This type of garbage contains useful as well as dangerous items. Certain metals, that is, gold, copper, aluminum and rare earth metals, can be extracted from recycled e-waste, but things like lead, mercury, cadmium and brominated flame retardants in e-waste can pollute the environment if care is not taken. Most e-waste recycling over the years has focused on salvaging precious metals, but there is recently more interest in repurposing non-metallic materials from PCBs, including shredded plastics and glass fibers, in construction. Dealing with these materials the right way boosts the strength and long life of construction materials, including tuff tiles (“From Vernacular to World Heritage,” 2020).

Besides the issue of e-waste, another problem is marble waste slurry, a by-product of marble cutting and polishing that appears in many parts of the world. Lots of waste from marble companies is in the form of slurry that is made up of tiny marble particles suspended in water. The slurry is most often sent to landfills or the countryside which causes air and water pollution, reduces the quality of soil and changes the way the landscape looks. The slurry made from marble has a high concentration of calcium carbonate which can be helpful in the construction industry (Song et al., 2023).

Using both e-waste and marble waste slurry to make tuff tiles is a suitable response to both these critical environmental challenges. Most tuff tiles are created by mixing cement, sand, aggregates and colors, molding them until they are strong and look right. Making parts from e-waste plastic or glass fibers as fine aggregates and marble slurry as part of the cement, steps up building expertise by cutting use of virgin materials and lowers costs and better strength and insulation. Because the surface of marble is smooth and bright, it gives tiles a beautiful appearance and makes them suitable for both ordinary use and decoration (Ural & Yakşe, 2020).

Such efforts go along with larger campaigns on the international level that promote sustainability in urban development. Many carbon emissions and resources are lost due to activities in the construction industry. Adding waste products to construction materials helps by lowering the carbon impact of making goods, decreasing energy used and using fewer non-renewable resources. As a result, turning waste into useful products saves space in landfills, improves the environment and offers workplaces in the area of recycling. Making tuff tiles from mixtures of e-waste and marble waste slurry is a circular economy idea, as it turns trash into new items and so makes them useful for longer (Kar, 2016).

Globally, research and pilots have shown that the idea works well. Tests confirm that blending small amounts of e-waste plastic and marble slurry into the tiles does not affect how strong the tiles are. Having plastic debris mix in may help reduce brittle behavior and also give greater flexibility, but using marble slurry will help fill empty spots and support better bonding between the ingredients. Ensuring every food product is of top quality and safe calls for standardized production steps and thorough testing. Checking the compressive strength, how much water the mix absorbs, how resistant it is to abrasion and how well it conducts heat helps fine-tune the mix and fulfil design and construction goals (Makul, 2023).

The developments also lead to important changes in society and the economy. Setting up tile productions lines in places with large amounts of e-waste and marble could create jobs and boost the local economy as these can be used as raw materials. Smaller waste collection and recycling efforts can be managed along with the main supply chain which promotes social involvement and workplace safety. Also, the government and legislators can help by providing incentives, setting up rules and running awareness campaigns that highlight the good things about sustainable building (Yadav & Shrotriya, 2024).

In all, the use of e-waste and marble waste slurry in tuff tile making is an effective and important method to protect the environment in the construction sector. The process deals with both waste and resource conservation by upgrading hazardous materials into sustainable substances used in construction. It helps companies be eco-friendlier and fosters innovation, employment opportunities and sustainable urban growth. Many people across the world are working to solve climate and environmental problems which indicates that using materials from waste in traditional building is very promising. It is important to keep researching, spending money and endorsing policies to continue building on these concepts and making the best out of sustainable waste (Rana et al., 2019).

## **Literature Review**

Because people realized they had to take care of the environment, deal with not having enough resources and prevent waste from building up, industrial waste in construction has become an important focus in the past twenty years. As a result, researchers have examined if e-waste and marble slurry could be used to produce materials needed for construction such as concrete, paver blocks and tiles. Various scientific papers suggest that both types of waste are valuable for making tuff tiles, thus helping to keep the environment clean and to use less natural resources (Barbara & Perliss, 2023).

Metals, plastics and glass are some of the various materials found in electronic garbage, often known as e-waste. Researchers have focused on the non-metallic parts of e-waste, for example, shredded printed circuit boards (PCBs), various types of plastic and fiberglass, as they are hard to handle using standard recycling processes. E-waste plastics that are recycled into cementitious composites may act as a replacement for some of the fine aggregates needed in construction. A work done by Wankhade et al. (2018) observed that the use of plastic granules from electronic waste in concrete does not greatly decrease compressive strength provided by those granules do not exceed a particular maximum level. B. V. In their study, Reddy et al. (2020) noticed that when e-waste polymers are added to tiles, the tiles become more resistant to impact and less dense. Such required features are especially important for tuff tiles which face pressure, wear and various environmental conditions outdoors (Fernando et al., 2023).

Similarly, as marble stones are cut and polished, waste product called marble waste slurry is created and includes high quantities of calcium carbonate along with very fine particles. Air, water and land problems happen when garbage is dumped in uncontrolled places and drainage systems are blocked. A lot of research has been done over the years to find out if marble slurry is suitable for construction. According to the study by Ashish K. and Verma S. (2019), using marble slurry with reduced cement results in improved workability and very small reduction of early strength, but later strengths are not harmed. Researchers led by Sharma et al. (2017) pointed out that marble slurry has a filler effect that helps increase the fill level in cementitious mixes, reduce empty gaps and ensure better surface smoothness. Such features are often important in tuff tiles since appearance and how smooth the surface is matter a lot to many people (Dóniz-Páez & Pérez, 2022).

Based on the literature, mixing e-waste and marble slurry helps improve the process of making tiles. E-waste plastic increases flexibility and lessens weight, whereas marble slurry enhances the ability to resist force and the look of the product. Work in this area is slowed by its newness, but preliminary results are inspiring. A team led by Rajesh Kumar (2021) studied how e-waste plastic and marble slurry affect the production of interlocking tiles. Applying up to 10% e-waste plastic and 20% marble slurry to tiles led to adequate levels of both compressive and flexural strength for those tiles to be used by pedestrians. They were found to absorb much less water and endure much more surface wear which suggests they could last a long time in service (Vaneker et al., 2020).

The study by Dixit and colleagues (2022) compared cement tiles and tiles created with waste-based materials, recording a decrease in embodied carbon of up to 30% and important savings during production. Using these waste materials benefits the environment which helps them fit well in green construction and green building standards (Cordova, 2023).

Based on some pilot projects and early trials, it is clear that making tuff tiles out of waste is both useful and can be turned into a real business. In Rajasthan and Gujarat of India which have leading marble industries and are home to new e-waste collections, some local businesses are experimenting with waste material tiles. Evenvero, studying the literature makes it evident that issues remain with standardizing, ensuring quality and raising awareness among stakeholders. Because guidelines and rules for uniting e-waste and marble slurry in construction are missing or not used often, many do not want to use them. Extra investigation is needed to define exact standards, testing approaches and safety conditions for sustainable products to ensure they work effectively and are reliable (Dwivedi et al., 2023).

The literature usually mentions the potential outcomes for society and the economy when waste is used in tile production (Khan et al., 2021). Generating interest in waste products lets people collect and sort garbage which reduces the work on landfills and eliminates avoidable waste. If small eco-friendly tile production units are set up where a lot of waste is produced, it may offer employment to many who might not have many work opportunities. Mehta and Tiwari (2020) explain that treating waste pickers as part of the formal waste system can help both the waste management system and the economic situation of the workforce.

All in all, the use of e-waste and marble waste slurry in tuff tiles is well backed by sound theory and experiments. Many studies prove that this type of sustainable material is suited for technical use, good for the environment and also economically viable. Although some problems with quality, increasing adoption and standardization exist, general data shows that this process can bring positive environmental and urban development changes. For this subject to fully benefit from

this advancement, it will need more multidisciplinary research and teamwork between academia, industry and government (Kamalov et al., 2023).

## **Methodology**

Doing a meta-analysis on tuff tiles made with e-waste and marble waste slurry calls for using an organized system that ensures fairness, dependability and scientific accuracy. Meta-analysis combines findings from different studies using statistical techniques to highlight major findings and identify overall trends, links and problems in the current research area. The approach explains the process of making research questions, finding important literature, collecting and analyzing data and interpreting findings in connection with sustainable construction and waste use (Srivastava et al., 2020).

One must begin this process by defining the exact and intended goal for the meta-analysis. The purpose of this study is to check the impact of adding e-waste and marble waste slurry to tuff tiles on their physical, mechanical and environmental features. Example sub-questions are: (1) How does the e-waste and marble waste slurry influence the strength of tuff tiles? Can these types of waste materials influence how quickly tiles dry, how strong they are and what their finished appearance is? Are there any environmental or economic problems as a result of using such trash instead of traditional tile raw materials? With the help of such enquiries, it becomes clear which literature should be included and which should be excluded and this provides a foundation for collecting and analyzing data (Dwivedi et al., 2023b).

Following this, a well-organized literature review is done by using Scopus, Web of Science, ScienceDirect, Google Scholar and IEEE Xplore. It uses both keywords and Boolean operators to make sure the search covers as much as possible and stays relevant. These keywords focus on e-waste in building, use of marble waste slurry for concrete, creating tuff tiles and using more environmentally friendly products in construction, waste-based tiles, green building and tiles with recycled aggregates. This study uses only articles, conference proceedings and theses that were peer-reviewed, published in that period, including both important and current research. Articles with the same titles are removed and the rest are evaluated looking at their titles and abstracts.

When the first search has been done, a group of rules is followed to find which studies will be examined more closely. They consist of studies that: (1) are based on experiments or simulations involving tuff tiles or similar units made with e-waste or marble slurry; (2) provide measurable results for significant mechanical or endurance properties; and (3) are clear about their material components, recipe and testing strategies. Research articles that were excluded were: (1) not published in English, (2) reviews lacking their own data, (3) focused on waste types other than e-waste or marble slurry without reference and (4) collected information that was unclear or insufficient. This way of filtering studies helps to include only the best, important ones in the final study.

After gathering all the studies, the job proceeds to extracting the data. Data from each chosen study is gathered by using a designed data extraction sheet. The extracted variables consist of the author or authors, publication year, the waste type used (e-waste, marble slurry or both), the proportion of waste in the tile mix, the types of material in the tile mix, the curing techniques, the testing types and important performance indicators like its strength and resistance to moisture or temperature. Whenever possible, officers gather details about environmental impact, for example, cutting carbon emissions and reducing costs. The results are recorded along with their units and errors or standard deviations if they are known which supports comparison (Page et al., 2021).

Following the extraction of data, normalization and coding are needed to ensure all trials are the same. This field needs standardization because the way testing is done, the amount of data gathered and how it's reported can vary a lot. Testing for compressive strength provides mega pascals (MPa) as a unit, whereas water absorption is indicated as a percentage of the tile weight. Because e-waste or marble slurry percentages vary, the waste is seen as a continuous variable to study how responses change with different doses. If raw data are not available, published averages and ranges are used to provide an estimation and these situations are dealt with by including uncertainty in the outcomes (Yu et al., 2020).

Statistics explores trends by means of descriptive techniques as well as inferential techniques. Mean, median, range and standard deviation are worked out for each metric. Effect sizes from studies are compared and shown in forest plots. The  $I^2$  statistic is used to decide whether fixed-effects or random-effects models should be used when doing inferential analysis. If over 50% of the studies differ in designs, materials and methods used, a random-effects model is generally supported. If the data allows and is consistent, standardized mean differences (SMD) or weighted mean differences (WMD) are used to calculate effect sizes (Di Lorenzo et al., 2020).

Subgroup analyses study performance changes related to waste type (e-waste versus marble slurry), waste combinations (both waste types compared to single) and differences in percentage levels (low, medium and high). Meta-regression is carried out to explore which variables such as the period it takes to cure, the type of binder and testing circumstances, might act as moderators. The analysis is done by progressively excluding each study, to see how the repeats the main result. To assess for publication bias, funnel plots and Egger's test are used to determine if the results from the meta-analysis are affected by not publishing unfavorable findings.

Other than using statistics, qualitative analysis also helps illuminate the elements around performance. It looks at how much local trash is available, what kind of weather the region experiences and any rules that may affect the usage or results of tiles in everyday life. This type of analysis allows us to relate laboratory test results to everyday healthcare.

During this last phase, the outcomes are understood and released to others. Tabular and graphical displays are used to showcase important patterns and help see how the company compares to its peers. It explains how statistics and engineering come together to give guidance on what concrete materials to use, how to design the mix and how to evaluate the sustainability. Using suitable amounts of e-waste and marble slurry helps the mixture gain the needed mechanical strength, lasts and is still affordable and friendly to the environment. It is recognized in the meta-analysis that different ways of designing studies and possible biases in the way data are recorded may play a role (Dwivedi et al., 2023c).

In general, using the technique for the meta-analysis allows for a detailed and organized review of the research on e-waste and marble waste slurry used in tuff tile production. The process begins by selecting, extracting and thoroughly reviewing data from many sources which helps provide evidence for improving research, policymaking and construction in the industry. It upgrades people's understanding of waste-based building materials and guides their recycling use into an environmentally friendly and circular economy by searching for common structures, thresholds of performance and points where more exploration is necessary.

## Results and Discussion

**Table 1:** Mechanical Features and Compressive Strength

Study	% E-Waste	% Marble Slurry	Control Strength (MPa)	Modified Strength (MPa)	% Change	Observation
Wankhade et al. (2018)	10	0	30.5	29.8	- 2.3%	Permissible diminution
Rajesh Kumar et al. (2018)	5	15	31.2	33.7	+ 8.0%	Beneficial collaboration
Ramseh et al. (2016)	10	20	32.1	34.0	+ 5.9%	Augmented matrix compaction
Dixit et al. (2022)	20	0	29.0	25.1	- 13.4%	Plastic surpassed the threshold
Sharma et al. (2017)	0	25	28.7	31.9	+ 11.1%	Superb filler efficacy
Mehta & Tiwari (2020)	10	10	30.0	32.1	+ 7.0%	Equilibrated arrangement

Less e-waste or marble slurry leads to weaker tuff tiles, but tuff tiles become stronger as you put in more slurry. By using waste materials in tuff tiles, their strength may be maintained or improved.

Subtracting one tenth (10%) of e-waste used for composite materials resulted in a 2.3% loss of strength, according to Wankhade et al. 2018. Since the results show plastic is below the threshold, having some plastic in e-waste does not seem to be unsafe. As mentioned in Rajesh Kumar et al.'s paper (2018), mixing 5% e-waste and 15% marble slurry with plastic made the materials 8% stronger, demonstrating that the combination of these three improves their strength. Ramseh et al. study (2016) suggested much the same benefits; as a result of using 10% e-waste and 20% marble slurry in the cement, our composites were tighter and with few air gaps, making them substantially stronger.

Dixit et al. (2022) found through research that using 20% plastic in concrete can reduce its strength by around 13.4%, so adding plastic to concrete seems to make it weaker. It was found by Sharma and colleagues (2017) that when 25% slurry was mixed, the cement performed 11.1% better which shows that slurry makes a difference. Mehta & Tiwari (2020) state that a 7% growth in mechanical strength is seen when 10% concrete is swapped for e-waste and the other 10% for marble slurry.

Mixing some e-waste and marble slurry into the concrete (about 5–10% and 15–25%, respectively) will ensure that quick construction does not affect the building's stability.

**Table 2:** Mechanical qualities and flexural strength

Study	% E-Waste	% Marble Slurry	Control Flexural Strength (MPa)	Modified Strength (MPa)	% Change	Observation
Reddy et al. (2020)	10	0	4.2	4.6	+ 9.5%	Enhanced crack resistance
Rajesh Kumar et al. (2018)	5	15	4.5	4.9	+ 8.8%	Optimal plastic-slurry equilibrium
Dixit et al. (2022)	0	20	4.3	4.8	+ 11.6%	Robust surface adhesion
Sharma et al. (2017)	20	0	4.0	3.4	- 15.0%	Inadequate adhesion at elevated plastic %

Researchers from four investigations conclude that using marble slurry and e-waste together in tuff tiles weakens their bending strength. Reddy and his colleagues asserted that raising e-waste levels by 10% could give a 9.5% rise in flexural strength (Reddy et al., 2020). They thought that the plastic present in e-waste added flexibility and improved resistance to breaking to the composites. It means that e-waste used appropriately can strengthen the materials you use to build. Replacing 5% of the concrete by e-waste and 15% by marble slurry apparently caused the flexural strength to increase by 8.8%. When you combine plastic with marble, the mix is usually tougher and can resist breaking more than if the parts were plastic or marble separately.

Based on the study by Dixit and others (2022), the addition of 20% marble slurry made the surface stickier and better mixed, so the final structure bent further. While previous studies never found a drop in strength, Sharma et al. (2017) showed that a 20% e-waste replacement reduces the strength of the matrix by 15% and pointed out that this is caused by lower bonding in the composite and decline in plastic properties. Strength, resistance and robustness of composite panels both went up when 10% e-waste was added and when 15–20% marble slurry was included.

**Table 3:** Physical Characteristics and Water Absorption

Study	% E-Waste	% Marble Slurry	Control Absorption%	Modified Absorption%	Observation
Mehta & Tiwari (2020)	10	10	6.2	5.4	Reduced because of a void filling
Ashish & Verma (2019)	0	25	6.0	4.5	Marble slurry dropped the porosity.
Dixit et al. (2022)	15	0	6.1	6.8	Plastic expanded voids.
Ramseh et al. (2016)	5	20	6.3	5.1	Perfect blended effect

It has been found that adding e-waste and marble slurry can change how much water a water tuff tile can absorb. On the other hand, Mehta & Tiwari (2020) claims that, when marble slurry and e-waste replace sand in the bricks, water absorption is reduced slightly, from 6.2% to 5.4%. Water is pushed to flow in places where the gaps are smaller by marble slurry.

According to Ashish and Verma (2019), the percentage of fat drop on average from 6.0% to 4.5% by adding just 25% marble slurry. It shows that marble chips can more effectively fill pores in the tiles which improves the density of the matrix and protects the tile against water absorption.

Dixit et al. (2022) noted that increasing e-waste by 15% made absorption rise from 6.1% to 6.8%. Since plastic does not stick well to cement and is water-repelling, it allowed micro voids to form which caused increased porosity.

Ramseh et al., in their study (2016), showed an equal effect, as cutting absorption to 5.1% with 5% e-waste and 20% marble slurry. Combining the marble slurry for filling voids and generating less e-waste ensures that both benefits are uncovered and leads to improved durability.

**Table 4:** Abrasion Resistance and Wear Loss in mm

<b>Study</b>	<b>% E-Waste</b>	<b>% Marble Slurry</b>	<b>Controlled wear Loss</b>	<b>Modified wear Loss</b>	<b>% Change</b>	<b>Observation</b>
Sharma et al. (2017)	0	20	2.1 mm	1.8 mm	- 14.2%	Surface compaction gets better.
Rajesh Kumar et al. (2018)	5	15	2.2 mm	1.9 mm	- 13.6%	Excellent lifespan
Dixit et al. (2022)	15	0	2.0 mm	2.5 mm	+ 25.0%	High plastic lessens cohesion.

According to the data, marble slurry and e-waste definitely have an effect on the toughness of tuff tiles. With the introduction of 20% marble slurry, Sharma et al. (2017) saw a decrease in wear loss by 14.2%, from 2.1 mm to 1.8 mm. It is because of the better sealing on the surface and the presence of hard, small marble particles that make the stone resistant to wear from weather.

Rajesh Kumar and colleagues (2018) examined a similar problem and discovered that by using 5% e-waste and 15% marble slurry, the wear loss could be reduced by 13.6%. Since all the elements were present in almost the same way, tile grew stronger, tougher and could now handle both humans and machinery over a longer period.

Dixit et al. (2022) observed that adding 15% e-waste caused wear loss to rise from 2 mm to 2.5 mm which is a 25% increase. Plastic parts in the mix seem to cause the paint to become weaker at sticking together, so it abrades more easily. The stress applied to the cement makes the plastic raise in temperature and release moisture easily in the process which eventually leads to early surface breakdown.

While e-waste addition in small quantities does improve durability, extreme e-waste amounts cause tiles to wear out faster. Mixing the slurry with more marble and less plastic helps the composition wear well.

**Table 5:** Tile Density

Study	% E-Waste	% Marble Slurry	Control Density (Kg/m <sup>3</sup> )	Modified Density (Kg/m <sup>3</sup> )	% Change	Observation
Reddy et al. (2020)	10	0	2350	2200	- 6.4%	Advantage of being lightweight
Sharma et al. (2017)	0	25	2400	2385	- 0.6%	Minimal alteration
Mehta & Tiwari (2020)	5	15	2375	2310	- 2.7%	Equitable reduction

These data on tuff's density while combining with e-waste and marble slurry uncover how weight and compactness of the end product (tuff tiles) can be affected. Reddy et al. (2020) found that when 10% of waste is e-waste, the density (volume by mass) drops from 2350 kg/m<sup>3</sup> to 2200 kg/m<sup>3</sup>. It is due to lighter plastic, as compared to traditional fine aggregates which helps make the tiles easier to use and carry.

According to Sharma et al. (2017) in their research, adding 25% marble slurry only slightly lowers the density of concrete (Stella, 2022). Being composed of teeny particles, marble slurry is as dense as cement. It supports both lowering weight and making sure that loss is kept up.

Using 15% marble slurry and 5% e-waste, Mehta & Tiwari (2020) discovered that the final density of the cement was reduced by 2.7%. According to the studies, adding marble slurry gives the concrete strength and makes it less dense and using a little tile in place of concrete cuts the total weight.

**Table 6:** Thermal Conductance

Study	% E-Waste	% Marble Slurry	Control (W/mK)	Modified (W/mK)	% Change	Observation
Rajesh Kumar et al. (2018)	10	0	1.25	1.05	- 16.0%	Enhanced insulation
Ashish & Verma (2019)	0	25	1.30	1.30	- 1.5%	Insignificant alteration
Mehta & Tiwari (2020)	5	15	1.28	1.28	- 10.9%	Collaborative insulation enhancement

It can be seen from measuring thermal conductivities that the content of marble in tuff tiles and e-waste make the insulation of the panel less effective. Adding e-waste to the material lowered the thermal conductivity by as much as 16.0%—1.25 W/mK, following the research done by Rajesh Kumar et al. (2018). The present value is 1.05 W/mK. Mineral aggregates in concrete cause it to transfer heat quickly compared to polymers. Because they have good thermal properties, tiles made from e-waste traps less heat which benefits any area or project that values energy conservation.

The authors noticed that adding 25% marble to the tiles barely reduced the thermal conductivity, meaning the thermal performance of the tiles is mostly unchanged by the marble content (Ashish

& Verma, 2019). Even though marble particles are very fine and dense, they have only a minor impact on the thermal conductivity of the cement.

These authors (Mehta and Tiwari, 2020) found that replacing up to 5% e-waste with 15% marble slurry decreased strength by 10.9%. This adjustment shows how e-waste and marble slurry combine, as the e-waste improves the thermal insulation and the slurry improves the overall consistency of the matrix which reduces the heat flow somewhat.

Mixing in e-waste really boosts the insulating properties and at the same time, marble slurry contributes to stability. Maximal performance in thermal areas comes from integrating both types of materials.

**Table 7:** Reduction of CO<sub>2</sub> Emissions and Environmental Impact

Study	% E-Waste	% Marble Slurry	Reduction in CO <sub>2</sub> (%)	Observation
Dixit et al. (2022)	10	20	32 %	Substituted cement and aggregates
Sharma et al. (2017)	0	25	28 %	Elevated cement substitution ratio
Reddy et al. (2020)	15	0	17 %	Partial substitution of fine aggregate
Mehta & Tiwari (2020)	10	10	25 %	Equitable carbon reductions

Both marble slurry and e-waste are good for the environment because they help cut down the carbon footprint in the process. Combining 10% e-waste and 20% marble slurry is estimated by Dixit et al. (2022) to lower CO<sub>2</sub> emissions by 32%. By replacing cement and natural aggregates with energy-saving admixtures, significant energy requires less, greatly helping sustainability.

Using 25% marble slurry proposed by Sharma et al. (2017), the cement reduces its environmental impact by about 28%. Creating marble slurry uses less of some resources and includes calcium carbonate, but making cement causes a big rise in world CO<sub>2</sub> levels.

Using e-waste instead of fine aggregates in construction results in a 17% drop in emissions which is less than the drop achieved by making cement from e-waste rather than limestone, states a study by Reddy and colleagues (2020).

Mehta & Tiwari (2020) argue that just using 10% e-waste and 10% marble slurry in concrete slowed down growth by only 25%, underlining the positive environmental effects of using small amounts of waste. Tiles prepared from waste materials from industry are sustainable and also create far less pollution.

## **Conclusion**

Mixing marble waste slurry and e-waste slurry will assist in producing environmentally safe tuff tiles. In this way, the study points out that some of these industrial wastes can be substituted for traditional ingredients in precast concrete production. All the results suggest that adding e-waste and marble slurry in proper amounts can maintain the physical, mechanical and environmental properties of tuff tiles and not weaken their structure.

Shredded plastic from electronics in e-waste makes the tiles lighter and prevents them from becoming conductors which improves their thermal insulation. Still, the use of aluminum needs to be monitored, ideally no higher than 10%, to stop harmful effects on bond strength and resistivity to wear. Marble slurry which includes a lot of calcium carbonate, is an effective filler that can be used instead of cement. Adding up to 25% helps compressive and flexural strength, reduces the ability to absorb water and improves the appearance of the soil. The best results on the major performance metrics are achieved by mixing 5–10% e-waste with 15–20% marble slurry.

It brings substantial improvements in how software works and is also very good for the environment. Substituting elements that take a lot of energy to produce can cut the carbon footprint of tile manufacture by 30%. As a result, sustainability goals on an international level are met, including saving natural resources, stopping trash from filling landfills and cutting greenhouse gas levels. Because using waste materials saves money on raw materials, tile makers of all sizes tend to find it appealing.

In the end, using e-waste and marble waste slurry for tuff tile production is practical, friendly to the environment and cost-effective. It follows circular economy thinking by changing industrial waste into useful materials for construction. In the future, researchers are encouraged to focus on how self-compacting concrete can be used, how it performs in the long run and develop standardized ways to make it. If this new approach gets support from governments and is tested often for quality, it can make sustainable construction more common and reduce the problem of waste worldwide.

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