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Sustainability Comparison for Steel and Basalt Fiber Reinforcement, Landfills, Leachate Reservoirs and Multi-Functional Structure

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Abstract

To a large extend sustainable construction of any structure greatly depends on the materials used in its formation. Traditionally, materials such as bricks, mortar, steels are still important components of most buildings. But modern technology is equally changing how materials are created and used.

Based on the above explanation, the objective of this paper was to compare the steel structures with basalt fiber reinforced concrete. As basalt fiber is still not wide spread, this paper focus on the advantages, usages and applications of basalt fiber reinforced concrete to solve construction and structural challenges. The method and analysis used in this paper was derived from research and works done by previous authors on similar topics. Previous research information show that producers and users of these materials make choice of building materials to depend on the area the structure is proposed to be built and on the taste and ideas given by the client. Their consideration is often devoid of environmental, psychological, social and economy factors. The research methods lead to the understanding on the use and importance of basalt fiber concrete for landfills, leachate reservoirs and multifunctional structure.

This paper helps structural users and engineers to know that green materials with good environmental characteristics that support nature are being considered as best construction materials due to what they are composed of. Waste and cost are also crucial as far as construction materials are concern. Even now, management of waste products from landfills specially leachates requires better construction designs in tropical region like Nigeria. More so, in line with the recent safe the climate calls, efforts to select the kind of material used in raising structures are becoming unavoidable.

Keywords: Steel; Landfilling and Waste; Basalt Fiber Reinforced Concrete; Leachate Pool Construction; Durability; Tensile.

1. Introduction

What is important in today's modern construction is the ability of the structures to withstand the test of durability, environmental support and sustainability of those structural materials for a long time. There is no doubt that there is an emerging evidence showing that structures are giving us new look of civilization. From the pattern of old building to the modern architectural and civil/structural engineering ecstasy of various structures seen as buildings, concrete tanks like pools, bridges, dams, hotels, towers, roads and railway lines to mention but a few. These buildings could be for residential, office, commercial or industrial purposes. The bridges may be for highways (roads) and railway lines. Dams

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and other hydraulic structures used to manage flood water, wastes-water, sludge, leachates pools, canals and its flow.

Structural steel is a steel construction material, a profile, formed with a specific shape or cross section and certain standards of chemical composition and mechanical properties. Structural steel shape, size, composition, strength, storage, etc., is regulated in most industrialized countries. Steel is generally known to be heavy. Therefore, it is high in embodied energy, when it has to be transported over long distances. Due to its wide range of structural qualities, it becomes a material of choice in certain situations. Steel can be recycled completely and when used in construction it can be designed for easy deconstruction and re-use of the structural sections.

In the verge of improving environmental degradation caused by some materials used for construction, energy conservation, corrosion risk, sustainability and environmentally friendly materials are important for the emergency of new products [1]. Perhaps, the reason structural companies nowadays are looking for new, better and economical materials to use for structural construction. A material that must be beneficial to both the industry and for the green future. Their efforts are currently yielding fruits as growth is seen in the use of composite materials in structures. In recent research, observation has shown new composite material been found. This material is known as basalt fibre.

The characteristics of Basalt fiber is described as a high performance non-metallic fiber made from basalt rock melted at high temperature. Basalt rock can also make, chopped basalt fiber, basalt fabrics and continuous filament wire when processed. Basalt fiber originates from volcanic magma and volcanoes, a very hot fluid or semi fluid material under the earth's crust, solidified in the open air. The basalt fibres do not contain any other additives in production, which gives additional advantage in cost. Basalt rock fibres have no toxic reaction with air or water, are non-combustible and explosion proof [2]. When in contact with other chemicals they produce no chemical reaction that may damage health or the environment. Basalt fiber has good hardness and thermal properties. Basalt fibers have been successfully used for foundation such as slabs on ground concrete [3]. The fabrics and filaments can be proposed for the production of landfilling materials for lining, fire proofs due to methane gas explosions, leachate collections due to the hardness properties for retention ability and other chemical reactions common in municipal solid waste management.

Our proposal for basalt is because the world's environment has been polluted by so many industrial functions. Some of the pollution is caused by the fusion from the production of structural steel. Based on this reason, sustainable and environmentally friendly materials that could serve better in reducing the pollution rate of the environment should be considered while replacing older ones.

This paper will be giving some important comparisons between steel structures and reinforced basalt fibre concrete in structures.

1.1. Methodology

A descriptive method was employed in the study suggesting proper achievement of set objectives for multi-functional and structural materials under study. We explored an available literature that reviews adequate comparison for Basalt Fiber Reinforcement and steel use in the Landfills and Leachate Reservoirs construction as well as Multi-Functional Structure constructions. Information was obtained from the academician base on paper publication, expert's opinions, libraries and internet desktop studies in a wide range. A versatile opinion was drawn from the pool of existing papers such as journals, textbooks, periodicals, newspapers etc. that served as a study information base used to analyse the merits and demerits of the material being studied. Facts and Figures measuring up to the expectations were used to do the comparative analysis and find a niche for leachate pool concrete structure material.

1.1.1. Reconstruction of Traditional Concrete with Modern Basalt Fiber Reinforcing Materials

Apparently, comparative literatures by some experts give insight about using concrete to raise structures. Concrete is widely used in several civil and military infrastructures. It is presently the most widely used construction materials as most structures contain concrete. In addition to the static loading, concrete structures will inevitably suffer the dynamic loading from events such as earthquake, explosion and impact during their periods of service; moreover, a variety of protective structures are vulnerable to artillery attacks and explosions [4, 5]. The normal concrete exhibits brittleness because of its weak resistance to cracking. When exposed under impact loading, the normal concrete usually exhibits a failure mode of collapsibility, which results in further serious safety problems in normal concrete structures.

The environmental impact occurs when salty, acidic or normal soil water reaches the steel in the structure; it causes corrosion and crack in the concrete. But we know that non-corrosive, non-magnetic and non-electric properties are necessary for a good serviceability. Therefore, the replacement of the traditional steel reinforcement has been required recently [6-9]. Defects properties of traditional concrete have significantly improved using fibers as reinforcement materials [6].

We found that effective measures that improve the impact-resistance behaviour of concrete usually involve the addition of fibers to the concrete. These dispersed fibers in concrete can effectively prevent the formation and propagation of cracks through bridging and significantly increase the toughness of concrete, thereby improving the

impact-resistance behaviour of concrete [32]. It has been observed also that the use of fibers alters the visco-elasticity characteristics of the mixture [33]; enhances its dynamic modulus [34], provides sensibility against humidity, improve flow coherence, and increase resistance against the rutting [35].

The majority of research into basalt fiber reinforced concrete has focused on its mechanical properties [24, 36, and 37]. Not long ago, some researches were conducted about the use of basalt fiber in hot mix asphalt concrete [38, 39]. Also, Sim et al. [40] investigated basalt fiber's durability and elevated temperature performance. The modern landfills have bioreactor characteristics features with unpredictable composition of chemical processes Schneider [41]. This material can be beneficial for leachates pool construction serving as reinforcing agent to avoid cracking and resistance. Anthropogenic actions around solid waste dumping sites, modern polymeric materials, heavily toxic chloroorganics, dioxins, phenols, methane gas, etc. constitutes priority pollutants of both soil and biosphere respectively purmal [42]. Nigeria has so many poor managed and unauthorized dumping pits/landfills where hazardous waste with high toxicity and reactivity goes uncheck. Under the influence of precipitation, they washed out, polluting the soil, surface and ground water bodies. For Nigerian ecosystem to survive, environmental safety structure are inevitable especially those that have the ability and affinity to withhold precipitation to avoid infections and invasions Alborov et al [3] and Hilde Kruse et al [43] due to constant exchange between biotic and abiotic components of energy transfer.

1.2. Expected Contribution to Knowledge

Proper and better utilization of building material to achieve the best output varying with part of construction being carried out, while outlining the best fit material for various aspect of building construction and structure type, with emphasis on the area of strength of each building structural material based on their peculiarity and strength. It will be of benefits to civil engineers, government institutions/building agencies, municipal solid waste managers, landfills leachate construction engineers among others.

1.3. Structural Steel

The process involved in manufacturing steel requires a lot of energy and the procedures are many. Molten iron is produced in the blast furnace where iron ore, coke sinter and flux are heated up to 900°C and the blast furnace is used continuously for 10 years. Oxidation of carbon in the process is done at very high temperatures and large amount of energy is involved as a result. According to Catalli and Williams [44], the most effective way of reducing the environmental impact of steel in construction is to design for disassembly. The existing structural steel members can also be re-used. The cost of transportation results to carbon dioxide emission. Steel is excellent for its speed and efficiency in construction. Steel's relative light weight and ease in construction allows a workforce about 10 to 20% smaller compared to a similar concrete-based structure being built. Steel structures also have excellent durability.

In recent constructions, steel is known with its new construction methods, steel buildings remain a popular choice for office and multifamily developers. The use of girder slab, staggered truss, and castellated beam construction enables lower floor-to-floor heights than typically expected in structural steel buildings. Figure 1 shows a skeletal structure of steel building. Steel delivers long spans of column-free space. Steel is capable to accomplish extremely long spans in structures and very open-bay footprints without intermediate columns. Steel is a very flexible material in terms of different ways to address design requirements.

Figure 1. Steel Structure Building

1.4. Reinforcement of Concrete Structure

Concrete is a mixture of cement, aggregates and water. Lately, new composite materials are being added to concrete for higher strength of the concrete on construction. An example of this composite material is **basalt fibres**. Cement is one of the biggest contributors of green-house gases [2]. The process in cement production involves grinding the cement ingredients and heating to very high temperatures to form clinkers. The clinkers are ground alongside with small amount of gypsum into cement powder. The energy consumed in the manufacturing process of cement is as a result of the high temperatures required to produce clinkers (up to 1870°C). With respect to cement, increasing the levels of mineral additions into cement up to 10% can help reduce the level of carbon dioxide emissions [45]. Reducing between 375,000 and 750,000 tonnes of carbon dioxide emissions can be achieved every year through this without any adverse effects on the performance of the concrete produced. Waste-derived fuels can be made use of in the heating process. Quarrying and mining of the aggregates does not add as much emission to the environment compared to cement. Concrete is the most versatile among construction materials[46]. It has good performance characteristics in many respects, such as strength, durability, abrasion, fire resistance etc. The most important constituent of concrete is the binding agent, cement being the most common. Concrete allows the designer to design very robust and durable buildings, taking advantage of its thermal mass by retaining it inside the building envelope to help regulate interior temperatures. An increase in the use of precast concrete in the building industry, offers advantages in terms of environmental impact, cost, sustainability and speed of construction.

Figure 2. Basalt Fibre Concrete for construction

Reinforced concrete structures are taking shape – many different shapes based on the designer's/ Engineer's/ Client's desire as seen everywhere around. We should always remember that concrete seeks the form. To the credit of the unique aesthetics achieved with concrete construction, these buildings offer some very real space advantages. Developers should realize that using cast-in-place reinforced concrete to frame a high-rise office building would yield more rentable space because of lower floor-to-floor heights. Reinforced concrete is an inventory material for the construction of most simple to complex structures. With significant improvements in the quality of cement and steel, reinforced concrete will continue to find new applications and wide spread use in this era.

2. Comparative Study on Steel Structure and Reinforced Basalt Fibre Concrete for Construction of Leachate Pools

2.1. Construction for Waste Management Facility

Municipal Solid Waste management is among other African continent's problem in this twenty-first century. The "leaching" of liquids from solid waste which happens when water gets into waste materials that are permeable, is inevitable due to weather conditions such as rainfall. This has the tendency of polluting both surface and underground water. The generation of leachate and its management has become a major challenge to several waste management organizations irrespective of their geographical location. The figure 3 below shows the distribution. We noticed through projections that urban municipal solid waste generation in 2025 using simple factorization is expected to grow in population and GDP as estimated per capita waste generation. Projections for each country were made based on the level of expected GDP (high-, middle-, or low-income) and an average range of MSW generation based on that income level. The table below shows the result. Modest adjustments for current experience and waste generation practices were made where appropriate. Similar to 'energy intensity' urban residents also exhibit 'waste intensity'.

2.2. Treatment of Leachates

Landfills are the most common dumping sites for solid waste in both developed and developing countries where the waste goes through several waste management processes such as recycling, re-using and composting to minimize the effects of waste on the environment and in most cases the goal is to achieve zero waste. Engineering appropriate technology for the desired results is more of a challenge due to the nature and components of leachates especially in

Nigerian soil. The considered parameters like physical, chemical or inorganic and organic components are important. The odour, temperature, colour, appearance, turbidity, conductivity and total solids in the leachates are necessary features to be considered for environmental promotion. The chemical components present are usually zinc, lead, copper, iron, sodium, nickel, calcium, potassium, pH, total alkalinity, chloride, total hardness, sulphate, phosphate, magnesium, nitrate, cadmium, chromium, and manganese etc. Hence, treatment of leachate from landfills is a major challenge to waste management institutions. The biggest challenge has being to find better materials that could be used to construct concrete tanks durable enough to withstand both chemical biological reactions without negative effects to the environment and for positive result. Basalt rein enforced concretes may stand the modern premium quality for basalt concrete leachate pools (BCLP). The figure below shows waste generation per regions components units of global indicators.

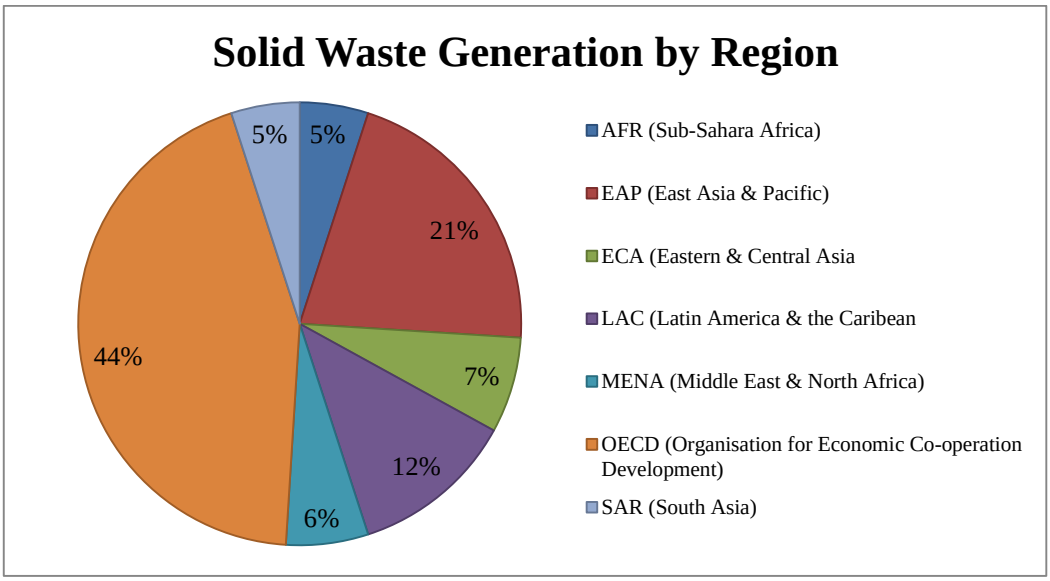

Figure 3. Showing Global Solid Waste Generation per region.

Table 1. Showing current Available Data vs Projections for 2025

Region	Current Available Data			Projections for 2025			
	Total Urban Population (millions)	Urban Waste Generation		Projected Population		Projected Urban Waste	
		Per Capita (kg/capita/day)	Total (tons/day)	Total Population (millions)	Urban Population (millions)	Per Capital (kg/capita/day)	Total (tons/day)
AFR	260	0.65	169,119	1,152	518	0.85	441,840
EAP	777	0.95	738,958	2,124	1,229	1.5	1,865,379
ECA	227	1.1	254,389	339	239	1.5	354.81
LCR	399	1.1	437,545	681	466	1.6	728,392
MENA	162	1.1	173,545	379	257	1.43	369,320
OECD	729	2.2	1,566,286	1,031	842	2.1	1,742,417
SAR	426	0.45	192,410	1,938	734	0.77	567,545
Total	2,980	1.2	3,532,252	7,644	4,285	1.4	6,069,703

Source: World Bank Urban Development report

In most countries the traditional method of dealing with leachate is to pump it to a waste water treatment plant for treatment or disposal. This method has been condemned by most scientists because of the capabilities of leachates to quench UV light during an ultraviolet disinfection. They also argue that the presence of metals such as ammonia also obstructs the biological process. There are modern methods of treatment which are on-site and avoid the pumping of leachates to waste water plants for treatment. These are designed in line with the characteristics of the landfill in terms of size, and availability of disposal sites near the landfill. This can either be a demarcated area or a water body where the treated leachate is discharged. The affinity of the basalt material for construction of leachate reservoirs are major concern because of the leakages which further extend pollution to the underground water.

2.3. The Cost of Construction

Reinforced Basalt Fibre Concrete

The basalt fibre in concrete mixture reduces the rate of damages that will be caused on structures during disasters like earthquakes. This ability in reduction is a cost benefit, an innovation that can provide a better repair of structures thereby supporting sustainable environmental promotion on structures. The cost of ready-mix has remained stable; however, supply and demand had gone up due to the impact on price and availability in the past decade, especially during times of extensive construction after natural disasters. To use Basalt fibres are generally cheaper compared to steel materials. Since most structural concrete contains steel reinforcement, any change in steel prices will affect it as well. But any increase in steel rebars for concrete reinforcement will lead to the replacement of steel rebars. If the same occurs for concrete reinforcement to basalt, rebars bears higher and better mechanical properties. Basalt fibers are most cost effective than the other high-temper Materials including E-glass, silica, ceramics, stainless steel and carbon by preventing rapid overheating and improving brake life [47]. Cast-in-place, reinforced concrete can be more quickly started on the jobsite but over time will take a larger crew longer to complete than steel, meaning higher labor bills. The cost of demolition and rebuilding steel cracked walls of leachates pools can be enhanced with basalt reinforced materials. Another interesting part is that the global economic crisis has pushed down the demand for steel which has consequently led to a decline in steel trade and prices. Steel production capacity on the global scale has continued to rise [1]. World total steel consumption increased from 705 million metric tonnes in 1999 to 1121 million metric tonnes in 2009, representing an increase of 59% [11]. The construction sector is one of the highest consumers of steel in the world, accounting for about 42% of world steel production [12]. The share of steel consumed in the construction industry is higher in developing economies than in developed ones. For example, 55% of finished steel consumed in China and 50% in India is used in the construction sector. It follows therefore that in a developing country like Nigeria where there is a lot of room for additional roads, railways, seaports, airports, industrial plants and such other facilities, the demand for and consumption of steel will continue to rise. Prefabrication off-site reduces labor costs since the crew will not be needed for as long as the building will arrive ready for erection and there is little metal work or waste on the site.

3. Discussions

3.1. Comparative Analysis of Reinforced Basalt Fibre and Steel

3.1.1. Safety of the Completed Structure

Reinforced Basalt Fibre Concrete

When basalt fibre concrete, is in thick columns or cores, is sturdy protection against debris and high winds. The core, containing the elevator, stairs, and power systems, is typically engulfed in 2-foot thick concrete that is capable of protecting the area from fire and some explosions. Reinforced basalt fibre concrete is highly resistance to fire also, without the need for additional fire-resisting materials. This is as a result of the basalt material in the concrete which can create an enabling environment for the mixture of toxic substances from landfill sites, including leachates, and other substances from decaying organic material which also impacts negatively on the quality of soil in the area where the landfill is located. With a thermal range of –260℃ to 982℃ and melt point of 1450℃ as well as low thermal conductivity 0.031-0.038w/mk, the basalt fibers are ideal for fire protection and insulation applications [4].

Steel

For Steel, Fire-proofing is easily attached to steel with a variety of spray on or attached materials that can match the need. Structural steel is very heat resistant on its own and the added fireproofing prevents widespread damage to other materials. Collapse as seen in earthquakes and bombings are prevented in steel frame buildings as they have redundancy of structure. The facility can be designed with progressive collapse to enhance safety in the case of disaster. Ductility of Steel is also proof against high wind loads and is the material of choice in seismic zones. Steel also has a lighter footprint that doesn't need a thick foundation.

3.1.2. Design Flexibility

Reinforced Basalt Fibre Concrete

Reinforced basalt fibre concrete can be molded into different shapes and pre-casting of walls for tilt-up construction has become common. Construction with cast-in-place reinforced basalt fibre concrete for high rise buildings can yield more rentable space due to lower floor to floor heights. Reinforced basalt fibre concrete can offer uninterrupted floor plates if it is carefully designed and properly engineered.

Steel

Steel has the highest strength to weight ratio of any construction material available in our present environment. Lower floor to floor heights can easily be created using girder slab, staggered truss, and castellated beam construction.

Extremely long open spans are possible using steel that would not be feasible in concrete.

Concrete and steel are both common and important construction materials. But the addition of basalt fibre to concrete is what lots of engineers have not really looked into. There are reasons for choosing one over the other, but as it shows, steel looks like a clear winner in our book. It is safer, is more flexible in design, easier to schedule, and has a higher availability than concrete depending on the area where the construction will take place. But generally, the addition of basalt fibres to concrete rules off lot advantages of steel structures to reinforced concrete structures. Plus, since steel is 100% recyclable with no loss of strength, the environmental impact is much lower.

3.1.3. Environmental Impact

Reinforced Basalt Fibre Concrete

Discovery through research shows that 50% of basalt fibre concrete are crushed and recycled; 40% are down-cycled to be utilized for hardcore in substructure works of a building or utilized in road construction; and only 10% is wasted mostly used for filling. Basalt fibre concrete structures have more advantages as if ventilated in the right way, the thermal inertia can save the user the stress ensued on heating and cooling costs of the building. Basalt fibre concrete floors, are poor conductors of current and heat, this gives it the advantage for use in high temperate regions. In cases of fire outbreak, the basalt fibre concrete structure will resist cracks thereby increasing the keeping the structure in the period and after the fire outbreak. This is a good option for the construction of landfilling sites and leachate treatment plants or pools where frequent fire outbreaks are possible.

Steel

Though steel is 100% recyclable just 85% of steel are been recycled at the end of its life. Due to magnetic properties that are found in steel, it is easily separated from other construction wastes, and this aids the recycling process making it more effective and easily carried out. Nevertheless, the energy employed in producing recycled steel is just about one-third of what is required to produce virgin steel from iron ore. Invariably resulting to less CO_2, less energy waste, and reduced resources being used to produce new steel. Even iron ore mining companies have been exposed to the green movement and made efforts to decrease the environmental impact involved in the production of new steel.

Other properties of steel that makes it environmentally friendly:

- Little or no need for repair and maintenance
- Little or no construction waste
- Steel is flexible in adaptation to various use and forms
- Heat Island effect are reduced in steel buildings

3.1.4. Availability

Reinforced Basalt Fibre Concrete

Basalt fibres and other aggregates in concrete are seen available in its natural state. According to reports, in the beginning of the year 2000, there was a shortage of cement that are used as binding ingredient for concrete, as a result of heavy construction needs in Florida after the hurricanes destroyed the coastal towns. Delivery rates also increased, and transport vessels had limited accessibility. This invariably led to another price hike and an unpredictable supply of concrete for building construction. This deficit was mainly influenced by small companies, builders and contractors, all of whom had low cash reserves. Despite the fact that the cement companies began to expand and are expected to increase their internal capacity by 2008, the offer continues to suffer during natural disasters. The use of basalt fibres in concrete, reduces the quantity of cement to be used and the concrete still retains a high concrete strength.

Steel

The steel industry is in no short supply, although there is a significant growth in construction activity in Asia, especially in China. In 2014, the United States produced 86 million tons; and the world produced 1.6 billion tons worldwide, and as of 2017, more than 5% increased to data for 2014 and seen from study and research. As a result of the economic crisis in most countries, production of structural steel has reduced or even stopped. Much manpower and resources are needed to manufacture structural steel. When there is low in production of this material, the availability will be low.

4. Conclusion

Steel and Reinforced Basalt Fibre Concrete are both important and valuable in building structure but are greatly dependent of several factors as previously discussed in this article and one of them may not necessarily be used in place of the other, as cases may arrive that both of them could be used together to achieve the utmost out of any said

construction being carried out. The management of landfill and formation of leachate remains a bigger challenge especially in tropical climates. In such climates the rate of decay due to high temperatures, humidity and rainfall makes it very challenging in managing leachate. A better well designed engineered basalt Fibre Concrete are one of the most tangible, durable, tensile, sustainable, strong and versatile building materials that can be used for construction. Steel and basalt fiber concrete properties are well x-rayed outlining the pro's and the con's to draw a conclusion on the best material as both have their peculiarity and function maximally in diverse and special condition depending on the nature and form of building structure to be constructed.

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6. Conflicts of Interest

The authors declare no conflict of interest.

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