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Life Cycle Analysis of Steel, Glass Fiber Rebar Polymer and Basalt Fiber Reinforcement Polymer

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Abstract

This study aims to identify an alternative material to steel with a lower environmental footprint while maintaining comparable performance, durability, and cost-effectiveness. We have used Life Cycle Assessment (LCA) as a tool for the present study. We have compared steel with Glass Fiber Polymer Rebar (GFRP) and Basalt Fiber Rebar Polymer (BFRP). There are four major steps involved in cradle-to-grave analysis: Goal definition, inventory analysis, impact assessment, and improvement analysis. Life Cycle Cost Assessment (LCCA) per unit analysis for each material considers raw materials, production costs, and market price comparison.

Major Findings: *BFRP or Basalt rebar or Basalt offers competitive performance at a lower environmental cost. Basalt rebar shows promise as a sustainable alternative to steel and GFRP. BFRP is better in performance in terms of less corrosion than steel and GFRP. Steel, despite its poor environmental performance (i.e. in terms of air emission i.e. NOx and SOx, and waste water quality) remains widely used due to cost-effectiveness. Based on the environmental performance the research concluded: Basalt > GFRP > Steel. The economic viability of steel still remains, but basalt offers better eco-efficiency. LCA proves that basalt rebar is a strong alternative for sustainability.*

Keywords: *Basalt Fiber Rebar Polymer (BFRP), Glass Fiber Reinforced Polymer (GFRP), Life Cycle Assessment (LCA), Life Cycle Cost Assessment (LCCA), Steel*

1.0 Introduction

A need for sustainable products is the need of the 21st century in order to support the nearly 6.5 billion world population. World raw steel manufacturing arrived at 1.8 billion tons in 2018, up 4.5% from 2017. As indicated by world steel, raw steel manufacturing expanded in all areas[1]. The iron and steel industry, having about 20-44 % of total energy demand is one of the many industries that could use an affable sustenance product. This expanded consciousness of environmental debasement has driven the consideration of makers and buyers towards environmental sustainability. This has led to discovery of various environmental tools that helps towards achievement of this sustainability. The choice of some fiber composite rebar affected the environmental-economic cost in various ways. In the first place, each fiber composite rebar has an economic cost, which relies upon the determination of a matrix and fibers. And yet the fiber composite rebar mechanical properties not just condition the measures of fiber composite rebar, but also additionally condition the measures of cement and steel reinforcement[2].

Life Cycle Assessment (LCA) is cradle to grave evaluation of an item or administration. It examines the effect of any item over a lifespan from the uprooting of crude materials to the scrap removal of its different parts. It plays a substantial role in economizing energy, preserving

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resources and economizing billions by forbidding early failure of important engineered component in a machine or material. It is also occasionally known as Eco-balance or Cradle-to-grave examine. LCA has four linked components *viz.* goal definition and scoping, life cycle inventory, impact analysis and improvement analysis.

An LCA is one of the apparatuses normally utilized to gauge the natural effect of an item or a procedure. This apparatus is a piece of a progression of universal measures planned for improving structures to empower better ecological administration[3]. Life Cycle Cost Assessment (LCCA) can be either acted in a convenient approach, which is called deterministic approach. A further developed approach could likewise be taken which includes endeavoring to diminish the vulnerability of future results. The deterministic methodology utilizes fixed accepted and evaluated values, the affectability approach thinks about the hugeness and vulnerability of recently made suspicions for the deterministic methodology[4].

An LCA is commonly an iterative procedure (for example its stages are rehashed as more date is collected or systems better comprehended). The effect evaluation serves to increment the information and comprehension about which of the natural data sources and yields are critical. This information can utilize in the gathering of better information for those sources and yields to improve the stock investigation. The conclusion of the

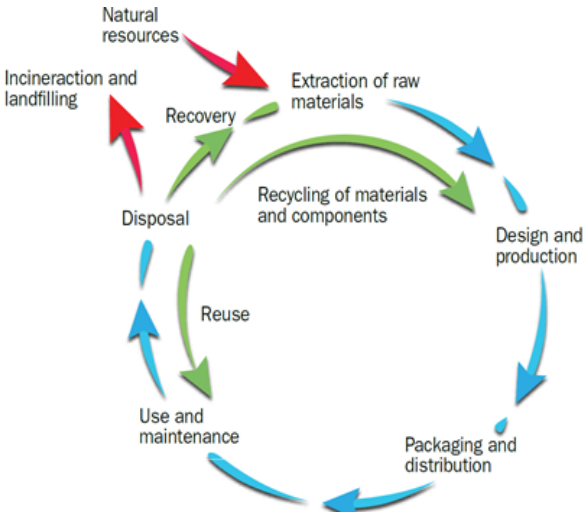


Figure 4. Life cycle assessment frequentative process[6].

LCA ought to be perfect to the objectives and nature of the examination. LCA is a methodology to access the ecological loads corelated with a thing, procedure or action by perceiving and estimating energy and materials used and waste discharge to the nature; to survey the effect of those vitality and materials utilized and discharge to the nature; and differentiate and access get to opportunities natural enhancements. The assessment incorporated the entire life cycle of the thing from a procedure or activity, wrapping, removing and taking care of raw materials; amassing shipment and conveyance; use, reutilize, backing, recycling and extreme removal[5].

Generally, steel manufacturing has been separated into two manufacturing processes. The first process utilizes iron mineral as a ferrous material and the second manufacturing process utilizes steel waste as a ferrous material and consumes minimal vitality than the first process[7]. The two products which might be used as an alternative to steel are Fiber Composite Rebar and Basalt Rebar. The study involves doing the LCA of all the above mentioned three products. The primary product, steel, which is the world's most exhaustively utilized metallic construction material is a compound of iron, carbon and manganese with modest quantities of silicon, phosphorus and sulfur. The substantial demand for steel implies that the prerequisite for alloying metals for steel production is huge and expanding. These components are required for delivering base steel, yet for producing ever more advanced steel grades that are both more grounded and increasingly safe, despite the advanced cooling, extinguishing and temper rolling can restrain the measure of compounds utilized[8].

The second, Fiber Composite Rebar contains fibers as reinforcement material having glass fiber fillers and polyester polymer matrix. The glass fibers reinforced the wax and make it more effectively safe. The fiber complex being featherweight and solid and has a capacity to assimilate and decrease tectonic waves. Presently it is one of the most engaging fortifications because of its superior, great properties and ease. It is comprised of silicon oxide and various additional oxide. Glass fiber composites or Glass Fiber Reinforced Polymer (GFRP), are impervious to immense heat and destructive nature and they additionally have sonar transparency. The positive side and negative side of utilizing fiber composite rebar material in the construction sector relies upon the plan

path, constructional feasibility and the sort of the work. The specific benefits of fiber composite applications are to offer extensive support existence with minimal rework than the different available materials[9].

Basalt Rebaris the third product, it is made from volcanic rock called basalt. It contains majorly silicon dioxide and aluminum oxides with traces of oxides of iron, magnesium and carbon. Basalt fibers are produced in a solitary stage process by dissolving unadulterated basalt rock raw material. It consists of 80% fibers and 20% resin. It has various advantages of its other substitutes in terms of high strength, high chemical stability, non-toxicity, ultraviolet resistivity and excellent elasticity and resistance to harm by harsh environments. For the manufacturing of Basalt Fiber Reinforcement Polymer (BFRP) reinforcing bars, the basalt fiber composites are installed in matrix polymeric resin, like Glass Fiber Reinforced Polymer (GFRP) rebars. In an exceptional grade manufactured BFRP rebar the unit weight of Basalt Fiber composite rebars is around 33% of steel, which diminishes transportation expenses and makes the rebar simple to deal with at the place of work, which interns in extra advantages to its execution[10]. The point of this study is the work of LCA which would additionally help in determination of the most appropriate material for development from the environmental perspective.

2.0 Literature Review

With the expansion in natural awareness, it has been important to survey that how modern activities are influencing the nature. Numerous industries have reacted to this awareness by giving "greener" item and utilizing "greener" procedures[11]. Structures are liable for huge material and vitality consumption in mechanical social orders. They represent 1/6th of the worlds fresh water utilization, 1/4th of its wood reap, and more 2/5th of its material and vitality streams[12]. Indian industry such as iron, steel and cement fabricate items for evenhanded development and yet expend enormous measures of vitality. India's overall conclusive vitality utilization was assessed at 449.27 M toe of which the industrial areas expended about 30%. The iron and steel division is one of the most vitality serious assembling sector, expending about 25% of the complete industrial vitality utilization. The Indian iron and steel industry is indispensable to the country's improvement endeavors and to help the required fast financial development. Vitality effectiveness and low carbon development have developed as key path ways to diminish the country's vitality power and emanations force[13].

The presentation of characteristic fiber composite has become hugely throughout the years. Accordioning to market survey, the world market on fiber composite came to US $2.1 billion with compound yearly development rate of 15% in the previous 5 years[14]. Utilization of Fiber Reinforced Polymer (FRP) composites for fortifying or restoration of structural members began hardly any decades back. The notable significant expense of FRP material may be preventive to its utilization. Be that as it may, FRP is a very serious material to utilize. It has an observable high quality also, stiffness ratio to density resistance to corrosion. The light weight of FRP gives noteworthy investment funds in labor cost[15]. The FRP is directly utilized an alternative for conventional steel reinforcement bars in the construction industry. Among all the FRP material the glass fibers are the most broadly and normally utilized material in construction market because of its simple accessibility and minimal effort of production[16]. Additionally, composites comprise of fiber in the lattice design and can be characterized by fiber span. Composites with prolonged fiber reinforcements are named as persistent fiber reinforcement although composite with small fiber reinforcement are named as irregular fiber reinforcement[17].

First manufactured in the mid 1930's, GFRP has gotten a staple in the structure business. Initially utilized simply for the construction of items, in 1967[18]. It has been utilized in gadgets, aeronautic and vehicle implementation *etc*. Glass Fibers are having astounding characteristics like immense strength, adaptability and opposition to chemical attack. Each kind of glass fibers have one of a kind property and are utilized for different applications as polymer complex. The mechanic, warm, water assimilation and vibrational characteristics of different GFRP composites were accounted[19]. The utilization of GFRP complex materials has reinforcement for concrete design to beat erosion issues has been developing[20]. The GFRP bars is a moderately advanced developing method for upgrading the flexural limit of actual RC components[21]. The GFRP has been affirmed to be the arrangement

as a significant advancement in reinforced concrete technology[22].

Basalt fiber are fabricated in a solitary stage process by melting unadulterated crude material. They are naturally protected and non-harmful, have high heat stability and protecting attributes and have an elastic structure[23]. The chance to utilize BFRP bars as inside reinforcement for concrete could be valuable in part of constraining the generally high deformability[24]. The attributes of Basalt fiber are explained as an elite non-metallic fiber produced using basalt rock liquefied at immense temperature. Basalt rock can likewise prepare, hacked basalt fiber, basalt textures and constant fiber cable when handled. Basalt fiber starts from volcanic slag, a boiling liquid or semi liquid material beneath the earths outside layer, harden in the outdoors. The basalt fibers don't contain some other added substances underway, which gives extra preferred position in expense. Basalt fibers have none poisonous response with air or water, are non-ignitable and blast evidence[25]. Utilizing BFRP textures to remotely reinforce RC members is a promising option in contrast to current RC structural fix and reinforcing techniques. BFRP textures, at the point when contrasted with elective Fiber Reinforced Polymer (FRP) material, are less expensive, show better strength attributes and have a lot higher break strain[26].

3.0 Research Methodology

The procedure utilized for this examination is initially information and data were accumulated through writing survey. The literature collected on impacts of steel, glass fiber and basalt rebar are the input for life cycle assessment.

Life cycle assessment is stated as "an objective of LCA is to analyze the environmental presentation of items so as to have the option to choose the least difficult". The term 'life cycle' alludes to the idea that for a reasonable, comprehensive appraisal of the crude material production, produce, dispersion, use and removal (including all intermediate transportation steps) should be checked. LCA is a normalized methodology, which gives it its dependability and clarity. The principle is given by the International Organization for Standardization in ISO 14040 and 14044, and express the four fundamental periods of an LCA.

3.1 Goal Definition and Scoping

An LCA begins with a precise proclamation of the objective and extend of the examination, which puts out to be setting of the investigation and briefs how and to whom the solutions are to be imparted. This is an important step and the International Organization for Standardization guidelines necessitate that the objective and extent of an LCA be clearly portrayed and persistent with the proposed function. The practical unit is concluded which is the unit to consider the effect of any product as the effect is not considered per product however per work of the product. For example, practical unit can be sway per litter of bundled refreshment. In the stage the effect classifications and strategies that will used to study the effect are likewise examined[27].

3.2 Life Cycle Inventory (LCI)

In this stage the information stock is made when the information is gathered of crude materials utilized and discharges. LCI examination incorporates investigation creating a supply of flows from and to kind for a unit system. Inventory stream incorporate commitments of water, energy and unrefined materials and emissions to air, field and water[27].

3.3 Impact Analysis

This time of LCA is planned for calculating the importance of possible environmental consequences dependent on the Life Cycle Inventory flow results. This stage the stock is introduced into natural pertinent data. It incorporates three stages which are distinguished which mean arranging stock parameter as indicated by the effect classes they add to, portrayal where potential commitment to each effect is examined and the last advance is weighing where total effect over the life cycle is surveyed this is typically a voluntary stage. It can likewise be known as the blend of the above mentioned two referenced stages of designation and portrayal.

3.4 Improvement Analysis

Life Cycle Assessment is a deliberate methodology to perceive, calculate, examine and assess information from the solution of the existence cycle inventory and additionally the existence cycle effect analysis. The solutions from the stock examination and effect analysis

are summed up during the interpretation level. This is the last stage where all the outcomes from the impact analysis are talked about and the effect is examine remembering the objective and utilitarian unit. This is last stage in an LCA where we can breakdown all information and come to end with regards to what are the effects of the particular item over a life cycle, which ought to be the best decision while thinking about various item (relative LCA) and so on[28].

4.0 Results and Discussions

When we aggregated the consequences of the stock, assessed the commitments to the chose environmental effect classes and obtained information from the interpretation, we would then be able to make determination as indicated by the objectives that have been set for the investigation. The results of this study are tabulated in Table 1, Table 2 and Table 3. Table 1 depicts raw materials requirement for one-ton production of material where as Table 2, and Table 3 depicts utility summary and environmental summary for one ton production of material.

It can be seen that in each material the effects caused during activity are exceptionally little contrasted with the production stage as the activity stage includes outflows because of transportation.

4.1 Cost Economics

The dynamic circumstances which LCA addresses must likewise in the long run phase the financial results of elective items or item structure into account. Be that as it may, neither the interior nor exterior financial aspects of the choices are inside the extent of created LCA system, nor are they appropriately tended by existing LCA instruments[31]. Crude material expenses differ as per to rebar type and cost variations can be critical. Epoxy, for instance, can cost 10 times the amount of as iron ore and three to five times as the amount of utility expense (Table 4). Hence, polymer covered rebar is more than 10 times expensive than steel rebar (Table 5). The cost of a specific kind of rebar can likewise be dependent upon periodic cost changes given its constituent materials. The expense of steel will change with the expenses of nickel and iron (which cost up to ten times as amount

Table 1. Raw material summary for one ton of material[29,30]

Item	Steel Rebar	GFP Rebar	Basalt Rebar
Iron ore	1.75 ton	-	-
Coke	0.75 ton	1 ton	2 ton
Limestone	0.25 ton	-	-
Mn ore	0.4 ton	-	-
Glass fiber	-	1 ton	-
Basalt rock	-	-	4 ton
Epoxy resin	-	2 ton	2.2 ton

Table 2. Utility summary for one ton of material[29,30]

Utilities			
Steam	4 ton	5 ton	5 ton
Power	2200 kwh	6 kwh	5 kwh
Cooling water	20 m^3	10m^3	8m^3

Table 3. Environmental summary for one ton of material[29,30]

Water Effluent			
Volume	17 m^3	8m^3	5.6m^3
Suspended solids	240 mg/l	150 mg/l	170 mg/l
pH	10.2	9.6	10
Residual chlorine	2120 mg/l	2000 mg/l	1900 mg/l
Air Emissions			
Particulate matter	0.65 kg	0.5 kg	0.4 kg
Carbon dioxide (CO_2)	1.2 ton	0.7 ton	0.45 ton
Sulphur dioxide (SO_2)	0.8 kg	0.5 kg	0.45 kg
NO_x	0.7 kg	0.1 kg	0.05 kg
Hazardous Waste			
Sludge	31.9 kg	21 kg	20 kg
Slag	55.5 kg	25 kg	26 kg
Metallic waste (Zn, Pb)	120 ppm	28 ppm	36 ppm
Recycle Potential			
Reuse	140 kg (14%)	320 kg (32%)	560 kg (56%)
Recycle	830 kg (83%)	530 kg (53%)	430 kg (43%)
Disposal	Landfill (3%)	Landfill (1.5%)	Landfill (1%)
Period of degradation	50-75 yrs.	Partially degradable (only polymer)	Inert material

Table 4. Raw material cost comparison of the materials per ton of production

Item	Cost or Unit (Rs)	Steel Rebar	Glass Fiber Polymer Rebar	Basalt Rebar
Raw Materials				
Iron ore	1900 /ton	3,325	-	-
Coke	10,000 /ton	7,500	10,000	20,000
Limestone	786 /ton	796.5	-	-
Mn ore	7000 /ton	2,800	-	-
Glass fiber	1,70,000 /ton	-	1,70,000	-
Basalt rock	11,050 /ton	-	-	44,200
Epoxy resin	3,00,000 /ton	-	6,00,000	6,60,000

of as chromium). The expense of steel composites with more nickel substances might be dependent upon the best change, therefore the cost is an important parameter in comparing and selecting the materials[32].

5.0 Conclusion

In conclusion, we can say that the correlation of the environmental execution of FRP composites and basalt rebar with that of conventional material solutions at an

Table 5. Utility comparison of the materials per ton of production

Utilities				
Item	**Cost or Unit (Rs)**	**Steel Rebar**	**Glass Fiber Polymer Rebar**	**Basalt Rebar**
Steam	1/ton	4	5	5
Power	5.5/kwh	12,100	33	27.5
Cooling water	0.4/ton	19	9.5	7.6
Production cost		26,544.5	7,80,047.5	7,24,240.1
Market price		40,000	10,00,000	9,00,000

item level requires a careful examination of the total life cycle of the product.

As shown in Table 1, a high measure of crude materials and vitality is needed to produce a ton of steel. Among all the air emission, CO_2 emission was found highest, in case of aqueous effluent the COD of effluent was found highest whereas metallic emission was found low. The steel production has maximum potential for impact indicator as energy resources. Green house followed by solid waste, acidification, eutrophication, eco-toxicity, summer smog, and human toxicity[33]. Out of all the utilities used in the steel production, power shows considerable impact on the environment.

The basalt rebar is more expensive than steel however, its safety to corrosion can adequately decrease its life-cycle cost and enable very low concrete cover depth permitting production of concrete beams with thickness as low as 1 inch[34]. Hence, cost is the major disadvantage in adopting alternatives to steel. The burden on raw materials in steel production can be reduced by achieving more recycling potential of steel.

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