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REVIEW ARTICLE

Using Basalt Fiber Reinforced Polymer as Steel Reinforcement - Review

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ABSTRACT - The production of affordable, lightweight polymers using sustainable composites reinforced with natural, eco-friendly fibers has recently attracted a lot of attention from both the research and manufacturing realms. Future construction of buildings must have the least negative impact on the environment while also being long-lasting. Basalt is the best material to utilize as reinforcement among natural fibers (animal, vegetable, or mineral) because of its advantageous qualities. The superior features of basalt rebar, such as its high tensile strength, low young's modulus, and corrosion-inhibiting properties, contribute to its operational excellence. This article summarizes the previous studies to investigate the use of basalt fiber-reinforced polymer (BFRP) bars as a substitute for steel reinforcement, emphasizing flexural strength, serviceability, and durability. That fits with the objective of this study, which is to analyse the most updated available data, compile the findings, and then identify any knowledge gaps that warrant future investigation. Moreover, the authors concluded following the review that basalt rebar might be used in construction as a more environmentally friendly and sustainable substitute for steel reinforcement.

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1.0 INTRODUCTION

Due to the rapid economic progress and improvement of living standards and to meet people's needs, the construction industry is booming at a fast pace. Concrete is the world's second most frequently used building material and the most commonly manufactured substance in the construction industry [1]. According to estimates, each person requires three tons of concrete annually [2]. However, concrete has poor tensile strength and ductility and is only effective against compression pressures. Therefore, reinforced materials are required to prevent the concrete from tensile and shear stresses. Reinforced concrete (RC), which is primarily used in construction, is a combination of concrete (cement, aggregate, water) and reinforcement [3]. Steel is a highly used material in construction time as reinforcement. Steel supplements concrete's compressive strength in columns and walls, offer additional shear strength over and above that of concrete in beams, and provides all the tensile strength wherever concrete is subjected to tension, such as in beams and slabs. Despite all of its benefits, steel reinforcement has several drawbacks, such as its high weight [4], susceptibility to corrosion [5], electrical conductivity [6], superior thermal expansion [7], difficulty in bending during installation [8], and limited size range [9]. Moreover, steel buildings are generally susceptible to corrosion, which drives up the cost of maintenance. The moist location, incredibly enormous in chloride ions following concrete breaking, is responsible for steel corrosion. Corrosion reduces steel bars' mechanical properties, shortening the structure's operational life and increasing security risks and financial loss [10]. Additionally, steel is neither a fire-resistant material; therefore, it is costly to maintain fireproofing. At high temperatures, steel starts to lose its properties [11]. During high temperatures, steel rapidly expands, which can be hazardous for the whole building structure.

Therefore, to overcome this situation, study on the mechanical behaviour of concrete structures reinforced by glass fiber-reinforced polymer (GFRP) [12], [13], carbon fiber-reinforced polymer (CFRP) [14]–[16] aramid fiber-reinforced polymer (AFRP) [17], [18] and BFRP [19]–[21] has been applied to determine the possibility and feasibility of replacing steel rebar with FRP reinforcements. However, due to their poor alkali resistance, GFRP and AFRP are vulnerable to the alkaline conditions found in concrete [22], [23], while GFRP and CFRP are still too unaffordable for use in conventional RC constructions [24], [25]. Among them, basalt has better tensile strength and modulus of elasticity than glass fibers and improved temperature tolerance and stability. BFRP is a newly launched reinforcing material [26], [27], which is inexpensive, easy to manufacture, has excellent acid resistance, extreme heat, corrosion, freeze-thaw, and has good resistance to vibration and impact loading [28]–[31]. BFRP is a more lightweight and durable building material than steel because basalt has a density (2600 kg/m^3) that is about one-third that of steel (7680 kg/m^3) [32]. In addition, basalt fiber production is more accessible and less expensive than other fibers [33]. According to a prior study, the energy necessary to generate basalt fiber in an electric furnace is around 5 kWh/kg, while the energy required to produce steel is roughly 14 kWh/kg [34]. Furthermore, BFRP bars do not rust or store moisture in harsh situations, allowing the concrete cover distance to be shortened [35]. These mechanical qualities are expected to have a well impact on the development of the sustainability performance of BFRP as a construction material. BFRP is therefore has been recommended as a strong and viable alternative to conventional rebar. The purpose of this article is to concentrate on the wide range of BFRP

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applications as an alternative to steel rebar in conventional RC and to provide a thorough overview of previous publications. In addition, the effectiveness of BFRP and conventional steel reinforcement in concrete structures is compared and highlighted in the current review.

2.0 RESEARCH METHODOLOGY

A systematic review was chosen as the methodology for this study because it is a good way to gather information from around the world in relation to a certain research topic or inquiries, consolidate the findings, and occasionally identify shortcomings [36].

The terms "basalt-based concrete" and "basalt as reinforcement" are used in this review study to search the publications' topics, keywords, and abstracts. Because of its reputation as a reliable database in the field on structure, Scopus was selected as the source [37]. For finding the articles, no time limit was chosen including all articles and conferences, books chapters were not included in this database. 300 papers based on the mentioned keywords were chosen by searching Scopus, as shown in Figure 1. The studies that were eliminated dealt with using basalt as a pavement or in the transportation sector since they did not deal with uses for concrete structures. As a result, 80 papers were gathered in order to conduct a systematic review on each paper's given topic. After examining those 80 papers, authors decided to include 60 papers in this review article. Other 20 papers were eliminated for low compressive strength and unstable or unsuitable structural implementation.

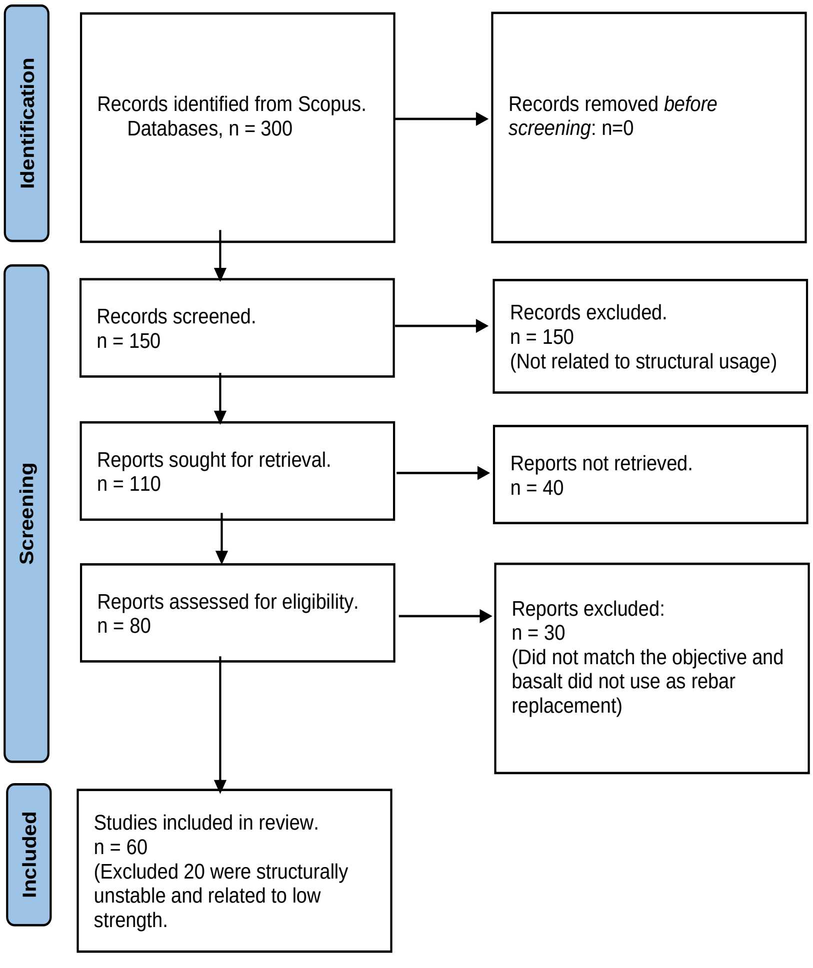

Figure 1: PRISMA flowchart for data collecting and screening process of this article

3.0 LITERATURE REVIEW

3.1 Elango et al. [38]:

This research investigated the flexural behaviour of reinforced concrete beams made with Portland Pozzolana cement and conventional steel and basalt rebar. Beams made of both traditional steel reinforcement and BFRP were experimentally studied for their flexural performance. The flexural behaviour of six rectangular concrete beams was tested. The beam specimen's length, width, and thickness were 120, 150, and 1000 mm, respectively. The reinforced concrete beams' primary longitudinal bars were both basalt and regular steel and were 8 mm in diameter. The shear reinforcement throughout the specimen has a 150 mm gap between each strand. For this experiment, researchers were used M30-grade concrete having a water-cement ratio of 0.5.

The test showed that the failure did not occur suddenly because the flexural reinforcement of the basalt was still in place and the beams reinforced with BFRP had a better bearing capacity than beams strengthened with traditional steel reinforcement. In addition, beams reinforced with BFRP undergo more deformation than those reinforced with conventional steel. A BFRP beam will bend three to four times as much as an ordinary steel-reinforced beam. This is because the BFRP rebar has less modulus of elasticity than standard steel reinforcing bars, making them less susceptible to deflection. In civil engineering, the findings demonstrate that BFRP may be utilized to replace traditional steel reinforcement in terms of long-term sustainability.

3.2 Wang et al. [39]:

In this study, researchers simulate a maritime environment and examine the long-term flexural behaviour of a beam reinforced with BFRP and steel. Nine beams were constructed using steel bar reinforcements according to the equal-rigidity concept, and then BFRP bars and grids were fabricated from them. After being subjected to accelerated corrosion treatment for 0, 3, and 6 months, the four-point bending tests were conducted. There were three distinct categories of specimens examined. These beams' span was 1700 mm, and their cross-section was 150 mm x 250 mm. Each beam had eight stirrups on one side, for a total of sixteen stirrups in the shear region, all of which were 70 mm apart. The stirrups were made from 8.0 mm steel bars having a yield strength of 400 MPa. The layer of concrete was 20 mm thick.

At the same time, the yield flexural strength, ultimate flexural strength, and secondary stiffness of BFRP-steel bar hybrid reinforced beams were increased by 15.9, 66.3, and 265%, respectively, compared to the beams of RC, while the maximum crack width was reduced by 37.8 % without corrosion. Using steel and BFRP bars, this research produced a hybrid-reinforced beam with superior flexural performance. Steel-BFRP hybrid-reinforced beams showed an increase of 3.7% in flexural strength after 6 months. The beam's flexural strength, measured by RC, was 104.1% after 3 months and 97.0% after 6 months. The steel beam RC's ductility increased due to the increased concrete's hydration, but the hybrid-reinforced beams' secondary stiffness and ductility changed slightly. Under 6 months of corrosion, the steel bars - BFRP bars and grid hybrid-reinforced beams had the narrowest cracks, with 55.0% of the cracks of the RC beam at the same time, but the steel-BFRP bars hybrid-reinforced beam had the narrowest cracks up to 3 months, with 58.8% of the cracks of the RC beam at the same time.

3.3 Abed et al. [40]:

The researchers numerically analyzed square and circular short columns and beams made of reinforced concrete (RC) reinforced with fiber-reinforced polymer composites. This project is divided into two parts. The axial behaviour of square and circular concrete columns reinforced with GFRP and BFRP bars and spirals and CFRP wraps is studied numerically. The second portion of the study examines the flexural behavior of RC beams reinforced with BFRP, GFRP, and CFRP bars, as well as the validation of the numerical model using actual testing. RC beams and two columns with BFRP bar widths of 16 mm and 20 mm, as well as a control column strengthened with steel bars, make up the experimental program for RC columns. An interaction diagram is being developed for a steel-reinforced column to verify the reliability of the FE model under varying eccentricities. Various eccentric loads are placed on the steel-reinforced concrete column.

After the FE model has been validated, a steel-reinforced concrete column interaction diagram is created, considering the characteristics of BFRP bars as the primary reinforcement. The BFRP-reinforced column is subjected to a variety of eccentricities. At certain eccentricity, the concrete column fails via crushing due to buckling. Beams reinforced with BRFP bars were modeled numerically, and the findings matched the actual data quite well. The results show that as the bar diameter grows, the beams' ultimate load-carrying capacity improves, but their ductility diminishes. When the overall area of the bars is kept constant, the load-displacement behaviour is the same regardless of the number of bars used. The CFRP bars outperform the BFRP and GFRP bars to boost the beam's load-bearing capability.

3.4 Rahman & Al-Ameri et al. [41]:

This research explores the bond behaviour of self-compacting geo-polymer concrete (SCGC) reinforced with BFRP bars, a recently created material. Various bar diameters (6 mm and 10 mm) and embedment lengths are tested to see how they affect the bond behaviour of BFRP-reinforced SCGC specimens. In this analysis, researchers will refer to the embedment lengths as 5 d_b, 10 d_b, and 15 d_b, where d_b is bar diameter (d_b) employed in the research. The SCGC cubes were $150\ mm \times 150\ mm \times 150\ mm$, while the bars used for reinforcing were 400 mm in total length. Twenty-one specimens, with varying specifications, are tested with direct pull-outs to determine the strength of rebar adherence to concrete. Results are compared to those of SCGC reinforced with traditional steel bars in accordance with the specifications of ACI 440.3R-04 and CAN/CSA-S806. Using artificial neural network (ANN) techniques, a bond strength prediction model was developed, expanding our understanding of BFRP bars' potential as internal reinforcement in self-compacting ambient-cured geo-polymer concrete.

While average bond strength of 10 mm steel-reinforced SCGC is greater than that of 6 mm or 10 mm BFRP bars, all BFRP-reinforced specimens displayed characteristics equal to standard Portland cement concrete. In a study comparing the strength of steel and basalt bars, the result was found that the steel-reinforced specimens could withstand maximum stresses (about 500 MPa). However, with a tensile stress of over 1100 MPa, the basalt bar broke before the peak was achieved.

3.5 Rudenko et al. [42]:

Fiber-reinforced plastic (FRP) rebar made of basalt fibers covered by a thermosetting polymer binder containing either micro or nano-particles is the focus of this effort to modify traditional rebar used in civil engineering. The most important findings from the production of composite reinforcement using either micro or nano-size particles are described. FRP's microstructure was studied using scanning electron microscopy (SEM).

This study also analyzed the retained plastic characteristics throughout the experiment, characterized by a lack of fragility. To determine the ultimate strength and elastic modulus of basalt plastically reinforced samples, the experimenter employed $corundum\ aluminium\ oxide\ (Al_2O_3)$ and $micro - silica\ (SiO_2)$. Composite base plastic FRP reinforcement bars with diameters of 8 and 10 mm were used in the study. Nanoparticles of alumina Al_2O_3 with particle sizes in the range of 5-60 nm were added to the matrix, and a mixture of $micro - corundum$ and $micro - silica$ was sprayed and baked around the outer diameter of the rod. In this case, at a pH of 7.74, the bulk density of the aqueous suspension of $micro - silica$ was between 0.16 and 0.21 t/m^3 in its unconsolidated condition and between 0.39 and 0.71 t/m^3 in its compacted state.

However, it was discovered that materials having a particle size of 10-500 nm, a homogeneous matrix distribution, and an average inter-particle spacing of 100-500 nm were quite strong. Composite reinforcement was also shown to have higher adhesion than steel reinforcement (1.5-2.5 times, depending on diameter) and standard unmodified FRP rebar (about 1.5 times). The elastic modulus and strength of dispersion-strengthened polymer composites containing SiO_2 and nano-sized Al_2O_3 particles are greatly improved compared to the original polymer materials. The physical and mechanical qualities of basalt plastics have been demonstrated to be more stable at temperatures between 350ºC and 400ºC, relying on the $organo - silicon$ and polyamide binders. According to Masuelli et al. [43], the aforesaid powders may be used in a wider variety of technical contexts if micro- and nano-sized powders are also used. This raises the possible temperature range to between 286-320°C. Basalt plastics based on $organo - silicon$ and polyamide binders are found to be more stable in physical and mechanical qualities when heated to 350-400°C, as reported in this study.

3.6 Meng et al. [44]:

In this study, researchers use a custom-designed method for ultra-high performance concrete (UHPC) with reinforcement manufactured from both regular steel rebar and basalt fiber rebar. UHPC is a novel building material that has received much attention in the last several decades. Static flexural and methane-air explosion tests were performed on the new components.

In the lab, three distinct varieties of UHPC specimens were produced and evaluated for their resistance to four-point bending. To illustrate the four-point flexural testing, a $400\ mm \times 100\ mm \times 100\ mm$ basalt fiber rebar reinforced specimen was employed. Two large-scale methane-air explosion experiments were conducted in utility tunnels, with tube lengths ranging from 12m to 20 mm and a grade C30 and UHPC specimens ($1800\ mm \times 400\ mm \times 90\ mm$) were tested with steel/basalt fiber rebar reinforcement. Pressure and deflection readings showed that the UHPC component reinforced with basalt fiber rebar behaved more ductile than the control specimen when subjected to an accidental gas explosion. This research examines the structural responses of basalt fiber-reinforced UHPC specimens subjected to static flexural and 9.5% methane-air explosion tests.

Basalt fiber rebar reinforced prism specimen performed better in static flexural test in terms of flexural strength and ductility index than steel rebar reinforced prism specimen. However, further research is needed to better understand the bonding forces between basalt fibers rebar and UHPC during high strain rate loading. Based on the current research results, it may be used as a reinforcing or strengthening material in conjunction with UHPC. A few test specimens showed a downward deflection in all tests, suggesting an adverse event occurred during the methane gas explosion. Based on the results of this research, a more complex test setup is needed to enhance turbulence and increase shockwave deflection in the response tunnel in order to achieve the desired explosion, such as the current methane explosion in a 20m tunnel.

3.7 Zhao et al. [45]:

As fiber-reinforced polymer bars are less stiff and ductile than steel rebar, it was suggested in this research to employ a post-tensioned, surface-mounted steel-basalt fiber-polymer composite bar. One way to make a composite bar out of steel and basalt fibers is to wrap a steel bar in a layer of basalt fiber-reinforced polymer. The nine produced and tested RC beams, including one control or calibration beam and eight beams strengthened with post-tensioned, surface-mounted steel-basalt fiber-reinforced polymer composite bars.

Beam samples have dimensions of 250 mm in height, 150 mm in width, and 1800 mm in length. All beam specimens, except the calibration beam, are reinforced with four steel bars and a bar made of steel and basalt fiber-reinforced polymer (SBCB). The bottom of the reinforced beams has open spaces that are $20\ mm \times 20\ mm$.mm in size.

When compared to the calibration beam, the crack, yield, and ultimate strengths of the beams reinforced with SBCBs from RC are increased by 32%-86%, 57%-71%, and 49%-89%, respectively. When the pre-stressing load increases, the predicted and experimental bending stiffness rises. As previously mentioned, test beams in this investigation were pre-stressed by 20%, 40%, and 60%. Increases in pre-stressing were shown to have a remarkable impact on cracking strength and the ability to regulate beam deformation. It's possible to increase the maximum strength, therefore. In this research, pre-stressing rates between 40% and 60% were determined to be optimal. However, the beams' precise specifications, including the concrete's ultimate strength and the tensile strength of the SBCB, must be considered to establish a fair pre-stressing ratio for actual projects. The residual strength of the SBCB may be lowered if excessive pre-stressing causes local compressive failure of the concrete.

3.8 Shamass & Cashell [46]:

This study examined the flexural behaviour of three types of internal reinforcement in a full-scale, simply supported concrete beam (sand coated BFRP bars, ribbed BFRP bars, and carbon steel reinforcement bars). This study focuses mostly on analysing the load-deflection response, cracking moment, ultimate capacity, fracture patterns, deflections, and crack widths. To assess whether BFRP reinforced concrete members are up to date with FRP standards, the experimentally measured values are compared to those predicted by American, Canadian, Russian, and European design standards. Five reinforced concrete beams were evaluated, two with sand-coated basalt FRP reinforcement, two with ribbed basalt FRP reinforcement, and one with 8 mm-diameter steel rebars. In addition, seven one-way spanning reinforced concrete slabs were evaluated, including three with sand-coated basalt FRP reinforcement, two with ribbed basalt FRP bars, and two with 8 mm steel rebars. Four-point bending loading conditions were applied to beams of $2000\,mm \times 200\,mm \times 125\,mm$, with a clear span of 1800 mm and a 500 mm gap between the loading points (i.e., the length of the constant moment zone in the center of the beam). Slabs with a size of $800\,mm \times 300\,mm \times 75\,mm$ were subjected to three-point bending tests, with force applied in the center of the 700 mm clear span.

Considering that the modulus of elasticity of steel is 3.6 times that of BFRP, the stiffness of the steel-reinforced beam was much greater when examining load-deflection behaviour. Sand-coated BFRP-reinforced beams behaved more rigidly than ribbed BFRP-reinforced beams. The sand-coated rebar slabs exhibited more considerable failure deflections than the ribbed BFRP slabs. Steel-reinforced RC members demonstrated a more fantastic breaking moment than BFRP-reinforced RC members. To add insult to injury, the cracking moments of the sand covered BFRP RC members for the same bar diameter were more significant than those of the ribbed BFRP RC members.

With the same reinforcement ratio, the experimental moment capacity of BFRP RC beams is greater than that of steel RC beams. Steel RC slabs have a more significant moment capacity than BFRP RC slabs, which is a topic of contention. Similar fracture patterns and crack propagation occur in steel and BFRP RC beams, although BFRP RC beams are more durable owing to their increased thickness. The cracking behaviour of the BFRP and steel-reinforced slabs was drastically different. The steel RC slabs exhibited less cracking than the BFRP RC slabs. Moreover, although the steel RC slab showed mostly vertical cracking with minor horizontal and diagonal cracks, the BFRP RC slabs revealed extensive cracking at the reinforcement level in all directions. According to Canadian and Russian standards, the BFRP RC's estimate of active-duty personnel deflection is too high. In addition, Eurocode 2 delivers the most accurate forecast for the BFRP RC. The ACI 440.1R-06 code offers the most accurate estimations for calculating the crack opening width of RC BFRP beams at the service moment compared to experimental data but dramatically overestimates the crack widths of RC BFRP slabs. In several tests, members reinforced with BFRP bars outperform their standard carbon steel-reinforced concrete equivalents, as shown by the findings of this study.

3.9 Rashid et al. [47]:

In this study, RC beams reinforced with steel, BFRP, and CFRP were tested in four different ways (Crack initiation and development, propagation and spacing, failure mode, and ultimate load). The CSA S806-12 code from Canada, the JSCE from Japan, and Zhang's models were all used to evaluate the study's findings. Fifteen RC beams ($1500\,mm \times 100\,mm \times 200\,mm$) underwent a four-point bending test. The distance between the border and the support was limited to 100 mm. Starting at 1 kN/min, the load was increased to 2 kN/min until beam failure was seen. Crack spacing produced experimentally and via Zhang's model using bond strengths from various codes are compared in Figure 2.

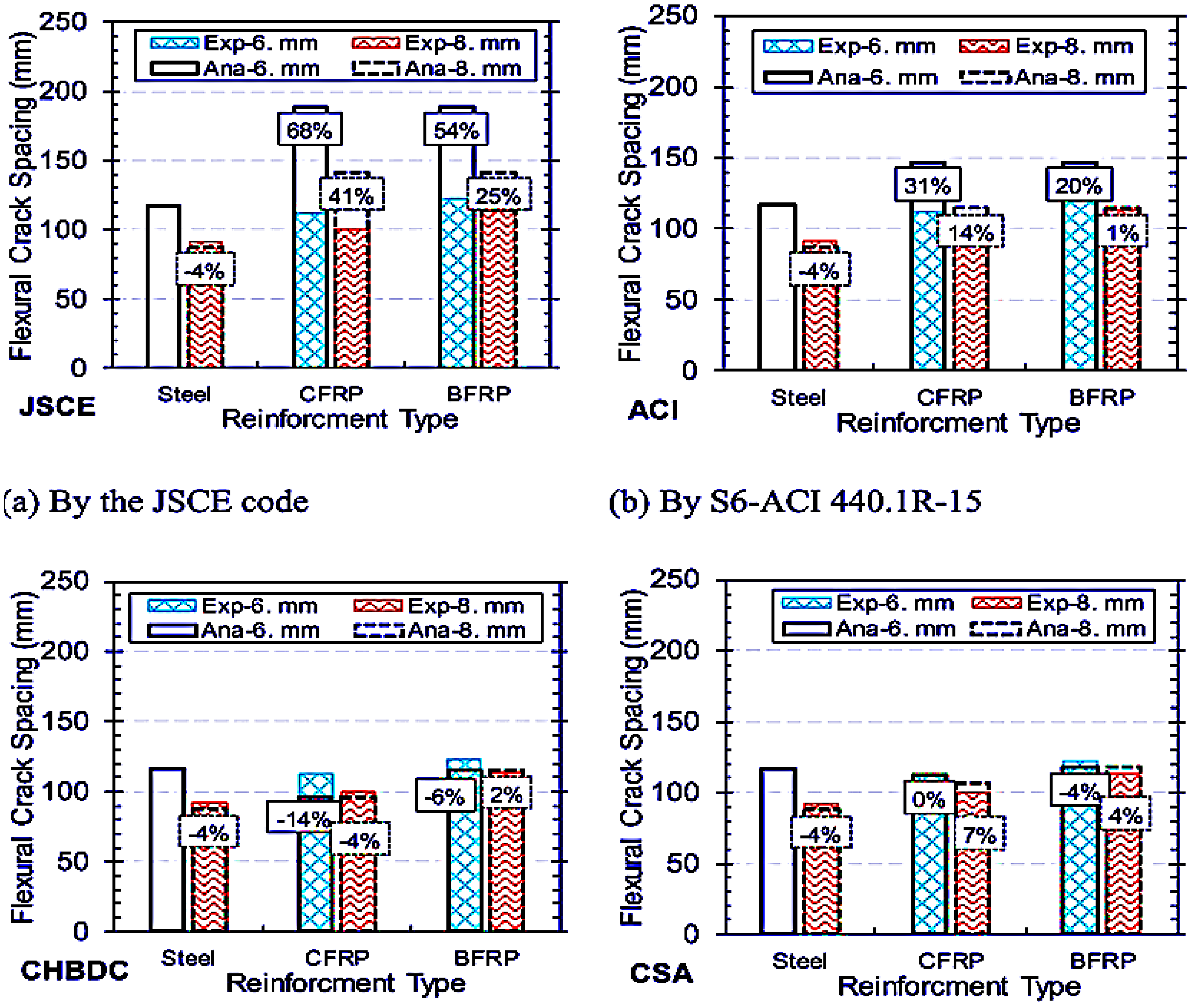

Figure 2. Comparison of experimental crack spacing obtained by Zhang's model by incorporating the bond strengths from different codes

The steel reinforcement had the best resistance to fracture initiation of any of the FRP bars, while the CFRP bar had the best resistance than BFRP bar. It was found that the crack spacing in the steel-reinforced beam was the smallest, followed by the CFRP-reinforced beam and then the BFRP-reinforced beam. The law of crack growth predicts this outcome. Zhang's model outperformed the JSCE and CEB FIP models in terms of the agreement between the analytical and experimental crack spacing of the 8mm steel bar, which he attributes to his inclusion of the steel-concrete bond strength. The failure mode shifted from flexural to flexure-shear when FRP bars were used in place of steel bars while maintaining the same reinforcing ratio. The ultimate load increased due to the cracking pattern and the substantially greater tensile strength of FRP bars. The ultimate flexural strength of both kinds of FRP-reinforced beams may be reliably estimated using the ACI 440.1R-15 code. To sum up, researchers found that FRP bars underperformed steel bars in terms of fracture start, crack size, and crack propagation rate. The steel-reinforced beam exhibited minor flexural fracture spacing compared to the FRP-reinforced beams.

3.10 Abed and Alhafiz [48]:

In this experimental investigation, researchers examined how the inclusion of various fiber types in concrete mixes affects the flexural behaviour of concrete beams reinforced longitudinally with BFRP bars. The primary objective is to investigate the viability of incorporating freshly manufactured basalt microfibers with a length of 12 mm and 24 mm into concrete to affects the flexural behaviour of BFRP-reinforced beams. An assortment of plain, basalt and synthetic fiber-reinforced concrete was used to create 12 beams with a desired compressive strength of 40 MPa (FRC). Basalt fibers of both 24 mm and 12 mm lengths were considered. Each BFRP-FRC beam was subjected to flexural testing using a four-point test configuration. To compare the two reinforcement types, the test matrix contained steel rebar and GFRP rebar reinforced FRC beams.

Results indicated that adding basalt and synthetic fibers to FRC beams raised their maximum moment capacity and enhanced their curvature ductility. Increases in the BFRP reinforcement content improved the flexural capacity of BFRP beams. The flexural capabilities of the BFRP bars were significantly enhanced due to the delay in concrete failure strain (more than 0.003) in the compression zone. The cracking behaviour of FRC beams throughout service and ultimate loads was enhanced compared to that of regular concrete beams, both in terms of crack spacing and quantity. Basalt fibers were marginally more effective than synthetic fibers in reducing cracking. The traditional steel reinforced FRC beams were substantially stiffer than the FRP ones because of the lower elastic modulus of FRP material. The steel FRC beam showed fewer and shallower fractures during service and ultimate stress compared to the BFRP, and GFRP reinforced concrete beams. The section capacity and stiffness responses of a given number of longitudinal BFRP bars were almost comparable for a given reinforcement ratio. The bridging action of the basalt fibers prevented fractures from spreading and widening over the 0.7 mm limit allowed under service conditions.

3.11 Ma et al. [49]:

Tensile and bonding properties of hybridized BFRP were studied. Experiments were conducted to determine the tensile strength of four BFRP steel bars and seven GFRP bars. In the tensile test, the GFRP bar was 1200 mm in length, whereas the BFRP-steel bar was 1240 mm in length and was 12 mm and 16 in diameter, respectively. The pull-out test bar specimens were made and evaluated in compliance with ACI Committee 440.3R-12. The four groups of samples included GFRP bars in various configurations: helically wrapped; uniformly sand coated, spirally wounded BFRP steel hybrid, and BFRP steel hybrid with wounds and sand coatings. Three GFRP bars (1260 mm in length) and three BFRP steel bars (1280 mm in length) were distributed to each group.

Comparisons to steel rebar reveal a 47% increase in tensile strength and a 169% rise in elastic modulus, whereas GFRP bars only exhibit a 5% improvement in tensile strength. The suggested BFRP steel bar also overcame the poor tensile strength of steel and the low elastic modulus of basalt fibers, demonstrating a more well-rounded mechanical property. Additional research was conducted utilizing four sets of surface treatments better to understand the bonding behaviour of the proposed rebar. The sand coated BFRP and GFRP specimens showed the most vital binding strength. However, the sand covering immediately peeled off the GFRP bars in the sand-coated samples, demonstrating brittle bond failure. Failure of the BFRP bars was significantly slowed by the spiral depressions on their sand-coated surface.

3.12 Duic et al. [50]:

This research analyzed the effectiveness of BFRP rebar in reinforced concrete beams. Eight full-size concrete beam specimens were tested, each reinforced with either BFRP or steel rebar. Shear and flexure test data for BFRP rebar-reinforced concrete beams were analyzed. The specimen beams' dimensions are 3200 mm in length, 275 mm in width, and 500 mm in depth, and made from concrete designed to have a 35 MPa. The tested materials included steel and rebar made of carbon fiber-reinforced plastic. There were two distinct stages for the beam samples. Phase I beam specimens exhibited a reinforcement ratio of 0.41%, whereas phase II beam specimens had a ratio of 0.83%. The strain was measured over a gauge length of around 100 mm using digital image correlation (DIC), as specified in the standard. The program VIC -2D, shown in **Figure 3,** was used to evaluate the material's strain.

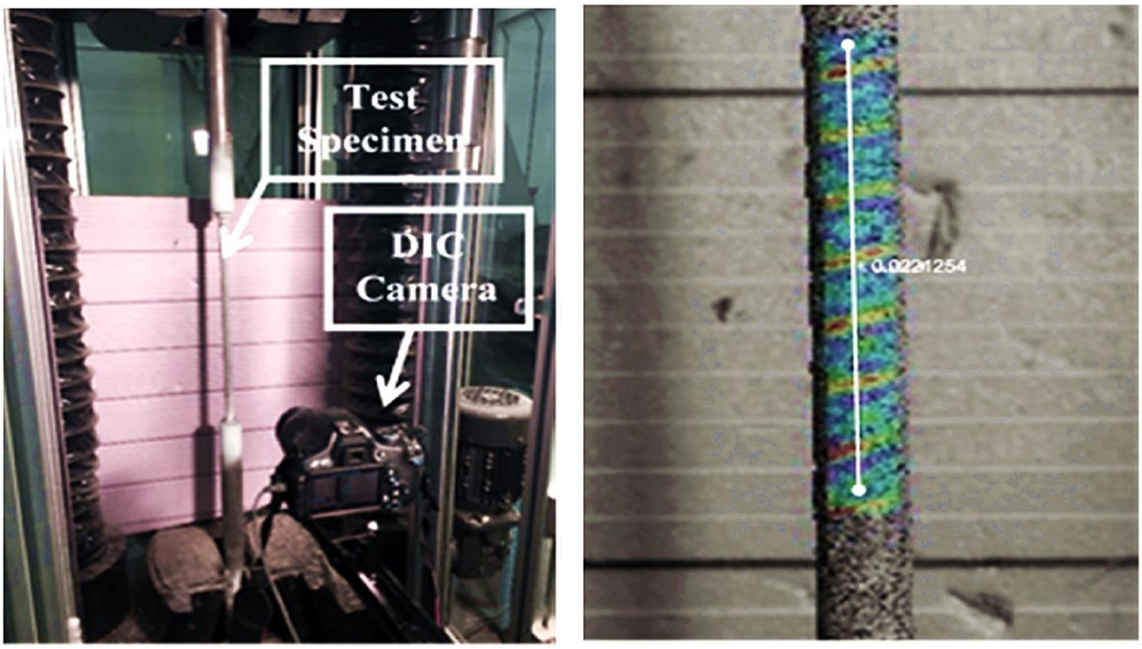

Figure 3. Tension test of BFRP rebar and DIC setup

In comparison to steel rebar-reinforced concrete beams, flexural and shear cracking in BFRP-reinforced beams was shown to be greater at low reinforcement levels. Beams strengthened with BFRP were also found to have sufficient deformability as measured by CSA S6-14. Testing showed that cracking moments were 30-50% greater for rebar-reinforced specimens. The study also revealed that the contribution of concrete to shear resistance (Vc) is 30-40% lower for BFRP-reinforced beams, and the shear failure may impact the design of BFRP rebar-reinforced concrete beams with BFRP stirrups.

3.13 Inman, Thorhallsson, and Azrague [51]:

This research examines the use of BFRP rebar in concrete beams and evaluates its mechanical and environmental performance compared to traditional steel rebar. Life cycle analysis (LCA) and material testing were also part of this review. Three steel-reinforced beams and nine BFRP beams were tested for strength and durability as part of the materials evaluation. Beams were pre-stressed using two used $2 \times 10\,mm$ diameter tendons. When compared to steel reinforcement of the same cross-sectional area, the tensile strength of BFRP rebar is nearly twice as strong, as evidenced by the mechanical data. Unlike steel tendons, which may reach 200 GPa in modulus of elasticity, BFRP tendons top out at 50-80 GPa. Reinforcing bars made from bonded fiber-reinforced plastic (BFRP) is very elastic, stretching by just approximately 3-4% at most. When the bars are not loaded, the strain is zero. Steel reinforcing bars have a very small elastic range—just 0.2% before it starts to act like plastic. Fig. 4 displays the BFRP bending test setup and cross-sectional test results.

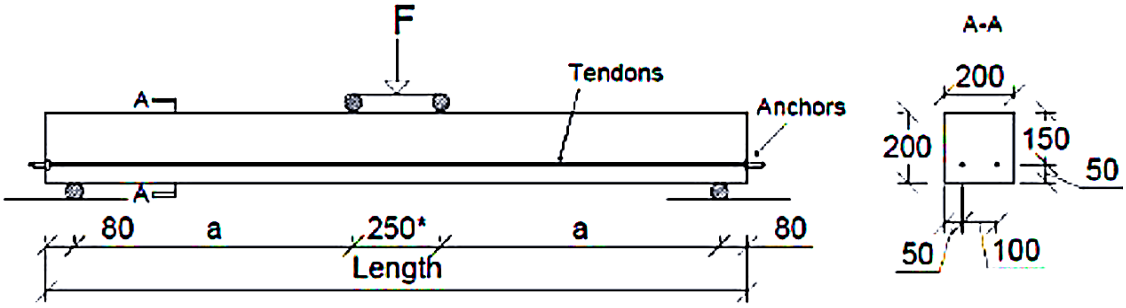

Figure 4. Unscaled Schematic drawing of the bending test setup and cross-section

This life cycle assessment aims to compare BFRP to traditional steel reinforcing bars in concrete beams to establish which material has less impact on the environment. This LCA comparison was performed using ISO 14040: 2006 and EN 15804: 2012 [52]. The LCA findings shown that the 1200 mm BFRP RC beam outperforms the 1250 mm steel RC beam across all 18 environmental factors. The embodied emissions of the BFRP RC beam were only 14.7 kgCO_2eq/ FU, whereas those of the steel RC beam were 23.7 kgCO_2eq/ FU, almost twice as much. Two main findings emerged when comparing the findings of the BFRP environmental study to the information provided in the EPD. Steel RC beams evaluated in this study had a GWP of 23.7 kgCO_2eq/ FU, comparable to the GWP reported in EPDs for precast steel RC beams (25.1 - 27.9 kgCO_2eq/FU). Second, the embodied emissions dropped dramatically to 11.3 kgCO_2eq/FU, when in-situ pouring concrete and 100% recycled steel were used instead of the EPD data. The study also discovered that the emission factors of BFRP tendons and reinforcing steel are close, coming in at 2.6 and 2.34 kgCO_2eq/kg, respectively. However, the total embodied emissions in BFRP RC beams are much lower than those in steel RC beams since BFRP has lower specific gravity and is three times lighter than steel.

According to the results, BFRP rebar is a viable future construction material that may replace steel reinforcement in concrete beams while still providing the same level of strength. It is anticipated that using BFRP in thinner concrete sections would result in similarly low emissions as conventional steel RC components. Thinner concrete members in BFRP-reinforced components are recommended for further study in this work to establish the optimal thickness for a specified performance.

3.14 Fan and Zhang [53]:

In this research, authors analyse the basalt-reinforced inorganic polymer concrete (IPC) beam, which combines the corrosion resistance and heat/fire resistance of both materials. With the help of fly ash, granulated blast-furnace slag, an alkaline activating solution, were used to make an inorganic polymer binder. Both evaluated the mechanical properties of a basalt-reinforced IPC beam and a steel-reinforced OPC concrete control beam. In comparison to a control steel-reinforced OPC concrete beam, the mechanical characteristics of a basalt-reinforced IPC beam were investigated. The anticipated value derived utilizing guidelines for FRP-reinforced OPC a concrete beam was contrasted with the measured ultimate flexural capacity of the basalt-reinforced IPC beam. A 150 mm concrete cube was subjected to GB/T 50081-2002 [54] after 3, 7, and 28-day uniaxial compressive strength tests. Rectangular concrete prisms $100 \times 100 \times 300\, mm^3$ and $100 \times 100 \times 400\, mm^3$, respectively) were tested at 28 days for their modulus of elasticity and flexural strength in accordance with GB/T 50081-2002 [55] and JTGE30-2005 [56]. To assess the flexural behaviour of RC systems, two inorganic polymers concrete beams (IPCB1 and IPCB2) width 120 mm wide, 200 mm high, and 2000 mm long were designed and manufactured.

At different curing times, the compressive strength of the IPC made with the suggested mix design was just a little bit lower than that of the control OPC. IPC has around 80% of the flexural strength of OPC concrete, but their elastic moduli are substantially similar, and the deflection of the basalt-reinforced IPC beam has been almost 4 times more than that of the control beam. Flexural stress caused similar cracking as well as fracture pattern development on basalt-reinforced IPC beams as in control steel-reinforced OPC beams, but the maximum crack width of such basalt-reinforced beams was almost twice that of the control beam. The fracture stress of the control beam was greater than the basalt-reinforced beam, although the crack deflection of the basalt-reinforced beam was about twice as large.

3.15 Urbanski, Lapko, and Garbacz [57]:

In this study, the researchers found the results of experimental research of the limit states for strains and stresses in concrete beams reinforced with flexural basalt fiber composite bars in order to establish the strength parameters and allowable cracking and deflections. This study evaluated BFRP-reinforced structures concerning the same structural member, reinforced with traditional steel in terms of their ductility, deformability, ultimate loads, and damage processes. This study compares the flexural performance of steel-reinforced and BFRP-reinforced beams under identical conditions.

The tested beams were composed of C30/37 concrete and reinforced with 8 mm diameter basalt bars with tensile strength determined by tensile tests. Here the authors also examined the behaviour of the beam deflection and cracking. The dimensions of all the tested beams are b × h × L = 80 × 140 × 1200 mm for the bending test program. Between the beams reinforced with BFRP bars and the beam with traditional reinforcement, beams with BFRP-reinforced performed much better in load testing. Due to the lower modulus of BFRP bars compared to steel bars, beams reinforced using BFRP deflected much more than the reference beam. Concrete beams reinforced with basalt showed much more deformation of their reinforcement (on average, three to four times more) than steel-reinforced beams. But by the end of the loading period, the standard RC beams' flexibility had reduced the gap to 40%. In basalt-reinforced beams, the average fracture width on the constant cross-section was 4 times that of reference beams. Since basalt rods have a lower modulus of elasticity than rebar, this might have major implications for the design of BFRP RC beams, especially in deflection and crack width.

Table 1 shows the critical comparison and summary of the obtained information based on the literature review. It is conspicuous that, basalt is much more suitable in the application of concrete structure in terms of its strength and durability properties. Although, this review provided an overview of its application, intensive study is recommended for unlocking its superior characteristics and limitations.

Table 1. Comparison and analysis of the findings obtained from the literature review

Reference	Type of concrete	Tests performed	Curing (days)	Result/Remark
Elango et al. [38]	Conventional Steel Reinforced Beam (SRB) and Basalt Fiber Reinforced Polymer beam (BFRB) using Portland Pozzolana Cement (PPC) and OPC.	Compressive, flexural, split tensile strength and chemical attack	7, 28	At 7 days, the obtained strength was lower as compared with 28 days. PPC concrete showed lower strength than OPC such as 11.3%, 19.4% and 8.6% lesser compressive, split and flexural strength at 28 days, respectively. BFRCB showed more deformation and PPC BFRB showed better chemical resistance.
Wang et al. [39]	Conventional steel concrete (SC), Basalt concrete (BC), Grid hybrid	Flexural strength, cracking and corrosion	0, 90, 180	Best ultimate flexural strength obtained in case of BC at 90 days which was 65.60% higher than SC. However, after 180 days a slight decrease in strength observed for BC, but it was still 77% and 6.40% higher than SC and hybrid, respectively. BC and hybrid showed minimal cracks and corrosion after 3 months.
Abed et al. [40]	Reinforced concrete (RC), Glass Fiber Reinforced Polymer (GFRP), Basalt Fiber Reinforced Polymer (BFRP) and Carbon Fiber Reinforced Polymer (CFRP)	Axial behaviour and flexural behaviour analysis with numerical modelling	-	As the longitudinal reinforcement ratio and spiral diameter rise, correspondingly rises the column's axial strength and ductility. The top performers in terms of boosting the beam's capacity are CFRP bars, followed by BFRP bars and lastly GFRP bars.
Rahman & Al-Ameri et al. [42]	Self-compacting geopolymer concrete (SCGC) reinforced with basalt FRP (BFRP) bars	Bond behaviour with the variety of bar diameter and embedment length	28	For conventional, regular Portland cement concrete, the bond performance of each of the BFRP-reinforced specimens was identical.

Table 1. (cont.)

Reference	Type of concrete	Tests performed	Curing (days)	Result/Remark
Rudenko et al. [42]	FRP rebars made of basalt fibers	Microstructural analysis and strength	28	The strongest materials have articles that range in size from 10 to 500 nm, are evenly dispersed throughout the matrix, have tensile strengths that are over 20% greater than those of conventional FRP rebar, and have more stable physical and mechanical characteristics.
Meng et al. [44]	Conventional steel concrete (CSC), Basalt reinforced concrete (BRC),	Static flexural test and 9.5% methane-air explosion tests	48 hour of hot water bath and 28 days room temperature curing	BRC showed higher flexural strength as compared with CSC with outstanding mechanical properties. However, downward deflection observed during methane gas explosion.
Zhao et al. [45]	Steel–basalt-fibre-reinforced polymer composite	Flexural strength, cracking, ductility and pre-stressing	-	Ultimate strength significantly improved up to 89%, superior ductile behaviour. Moreover, higher pre-stressing (60%) significantly increased the cracking strength.
Shamass & Cashell [46]	Sand-coated BFRP, ribbed BFRP, conventional carbon reinforced concrete (RC)	Cracking moment, moment capacity, crack pattern	28	The highest cracking moment observed in case of RC as its modulus of elasticity is significantly higher than that of others. Moreover, cracking pattern shorter in RC than others.
Rashid et al. [47]	RC, BFRC, carbon FRC (CFRC) beams.	Ultimate load, crack resistance	-	Ultimately load significantly increased up to 55% for BFRC-8 (8 mm diameter) compared with RC. However, RC provided better cracking resistance than FRCs.
Abed and Alhafiz [48]	BFRC and Glass fiber concrete	Flexural behaviour	28	Increasing BFRC reinforcement improved the load bearing capacity.
Ma et al. [49]	Basalt FRP and steel FRP	Tensile and bonding behaviour	28	Tensile strength and bonding behaviour significantly improved in case of basalt FRP.
Duic et al. [50]	BFRP rebar and conventional RC	Flexural behaviour and shear cracking	28	BFRP rebar reinforced beams showed higher flexural and shear cracking than comparable steel rebar reinforced concrete beams due to their low reinforcing ratio. In addition, satisfactory deformability was shown using BFRP-reinforced beams. When compared to BFRP rebar reinforced specimens, cracking moments for specimens reinforced with steel rebar were found to be 30–50% higher.
Inman, Thorhallsson, and Azrague [51]	BFRP rebar and conventional RC	Mechanical and environmental performance	-	Compared to steel reinforcement, BFRP reinforcement has a lower elastic module, less embodied emissions, and a better environmental profile.
Fan and Zhang [53]	Inorganic polymer concrete with basalt reinforcement	Flexural behaviour	28	Under flexural loading, the development of cracking and fracture patterns in the basalt-reinforced IPC beam were comparable to those in the control steel-reinforced OPC beam.

4.0 FURTHER RECOMMENDATION

Although this review study intended to focus on some of most updated information, but still many unknown properties need to be found out. Therefore, further extensive study should be conducted. For instance,

- Application of BFRP for self-compaction concrete and geo-polymer concrete.
- Need to compare the performance with many other FRP materials to get more authentic results.
- More study regarding compressive and tensile strength should be conducted.
- Non-destructive tests such as UPV should be conducted.
- Self-healing capability is a new topic to investigate.
- Fracture mechanism and cracking patterns should be conducted extensively.

5.0 CONCLUSION

We found that basalt fiber does have the benefits of being very resistant to corrosion, lightweight, and relatively easy to work with. Thus, it is the ideal component to be used as a reinforcing material in concrete buildings, particularly maritime constructions. Superb strength, around triple that of standard steel bars. Due to their high heat resistance, those materials are ideal to use in RCC construction because of the volcanic origin from which they were generated. With a relatively uniform chemical composition, a massive supply, and the capacity to generate fibers within molten states, basalt is a good raw material for fiber production. The rebar has basalt fiber, which is 80% of the material, giving the reinforced concrete superior mechanical properties. Where severe corrosion is an issue, it might be utilized instead of steel bars. Unlike carbon fiber, basalt is abundant in nature, making it cheap to produce and use. In the end, we may infer that basalt fiber is a viable replacement for more conventional reinforcing materials like glass, carbon, steel, etc.

6.0 AUTHOR CONTRIBUTIONS

Kamrul Hasan.: Conceptualization, Research paper analyzing, Writing- Original draft preparation, Writing- Reviewing and Editing

Md. Toriqule Islam.: Analyzing, Writing- Reviewing, modifying and editing as Reviewer's comments.

Tusdid Sabur Tohfa.: Visualization, Plagiarism.

Fadzil Mat Yahaya.: Supervision, Writing- Reviewing and Editing.

All authors have read and agreed to the published version of the manuscript.

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8.0 DATA AVAILABILITY STATEMENT

The data used to support the findings of this study are included within the article.

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10.0 CONFLICTS OF INTEREST

The authors declare no conflict of interest.

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