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Composite Material Using Basalt Fiber

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ABSTRACT

Basalt fibre is a high-tech fibre product that is both healthy and environmentally friendly, as it does not harm the natural world. The military and civilian communities alike make extensive use of it. There is great theoretical and strategic value in expanding our understanding of the characteristics of basalt fibre and its composite materials. Mechanical properties, acid-alkali resistance, electrical properties, wave permeability, non-conductivity, sound insulation, and insulation performance are all areas where basalt fibre excels over glass fibre, carbon fibre, and aramid fibre. The aforementioned advantages suggest that combining basalt fibre with a suitable substrate can boost material performance. Due to its high thermal resistance and low specific sound absorption, basalt fibre and its composites are used in the production of high and low temperature protective clothing and sound insulation materials. Its exceptional properties make it useful in many fields apart from conventional manufacturing.

Keywords: Basalt fibre, Composite, Thermal resistance, Environmentally friendly

1. INTRODUCTION

Engineering materials have always been pushed to their limits by the rapid pace of technical growth, but in the last century, new materials have been developed at such a rapid pace because requirements for structures, automobiles, etc. are changing so rapidly. Engineers have arranged diverse materials in ways that have qualities superior to that of the individual constituents, all in the pursuit of eking out greater performance from the materials at their disposal. All too often, the demands of cutting-edge technology exceed the capabilities of the metals, ceramics, and polymers that have traditionally been used in their construction. This is particularly true for building supplies and transportation equipment. Composites are quickly becoming a practical substitute for metal alloys in numerous industries, including building, transportation, maritime and aerospace, and sports equipment, among others. Since almost no materials are employed

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today in their purest form, composites are made by combining dissimilar components to achieve a desired effect that one or more of the constituent materials cannot achieve on their own. Composites have been around for a while. Composites have been around for as long as humanity has. There is a composite nature to the human body, consisting of both bone and muscle. Although their origins are shrouded in mystery, composites have been mentioned throughout history. Adobe bricks, one of the earliest composites created by humans, may have been the first. wherein the Preform was made of grass or straw, and the Matrix was mud.

Two components, a textile skeleton for reinforcement (known as a "preform") and a binding adhesive (known as a "matrix"), work together to form a textile composite. Reinforced fibres used in polymeric composites have been increasing in production and breadth of use on a global scale. Fiber composites have many benefits over traditional materials, including resistance to corrosion and chemicals, inertness, low heat conductivity factors, high specific mechanical properties, low weight, and high operating temperatures as well as long service lives and low design and installation costs. Adding fibre reinforcements to composites is a common practise for increasing the material's strength. Glass fibre is the industry standard for reinforcing resin. Carbon fibre, other plastic fibres, and natural fibres are just a few examples of reinforcement fibres.

Textile composites have two main components: a textile skeleton for reinforcement (known as a "preform") and a binding adhesive (known as a "matrix") material to keep the skeleton integrated into a desired form. Reinforced fibres used in polymeric composites have been increasing in production and breadth of use on a global scale. Fiber composites have many benefits over traditional materials, including resistance to corrosion and chemicals, inertness, low heat conductivity, high specific mechanical properties, low weight, high operating temperature, long wear life, and low design and installation costs. Adding fibre reinforcements to a composite material is a common practise for increasing the material's strength. The most typical type of fibre reinforcement used in resin is glass fibre. Carbon fibre and other plastic fibres are two examples of reinforcement fibres that can be processed appropriately for disposal. To give just one example, the incineration of waste composites made from glass fibres results in a lot of black smoke and unpleasant odours, and the fusion of glass fibres frequently damages the incinerator. Since synthetic fibres do not biodegrade easily, the reclamation process also creates a sizable environmental burden.

1.1 History of basalt

The Romans made extensive use of natural basalt as a paving and building stone, so its versatility has been known for a long time. Extruding fibre from basalt was first proposed by the Frenchman Paul Dhé, who in 1923 was awarded a patent in the United States for the process.

Starting in the 1960s, both the United States and the Soviet Union (USSR) began exploring BF's potential military uses. Prof. R.V. Subramanian of Washington State University (Pullman, Washington) studied the composition of basalt extensively in the northwest United States, where large basalt formations are concentrated. He investigated the relationships between basalt's chemical make-up and the extrudability conditions and physico-chemical properties of the resulting fibre. The Ukrainian scientific research institute received the first BF samples in 1959–1961. In 1963, the first continuously operating BFs of acceptable quality were manufactured using laboratory equipment. The first article about BCF appeared in "The glass and ceramics" magazine in 1963.

In the 1970s, US glass manufacturers mandated a research strategy that prioritised the study of glass fibre over BF. As a result, Owens Corning was able to successfully develop S-2 glass fibre, a superior type of glass fibre. At the same time, the USSR's Defense Ministry nationalised the research done in Eastern Europe, which had previously been done by separate groups in Moscow, Prague, and other locations, and concentrated it in Kyiv (Ukraine), where the technology was developed in closed institutes and factories. Research conducted in the Soviet Union prior to its dissolution in 1991 was declassified and made available for use in the free world. In 1985, a factory close to Kyiv designed and commissioned the first industrial installation for CBF production. The basalt processing facilities in Sudogda, Ukraine, and Georgia were all constructed in the Soviet Union towards the end of the 1980s. These days, modern continuous fibres can be developed from basalt stones, and there has been a lot of work done in this area recently. Modern manufacturing processes have brought the price of BFs down to the same level as, or even lower than, that of glass fibre. The many patents protecting the methods and machinery used in BF production.

Some former Soviet Union countries (Georgia, Ukraine, and Russia) and China are now the primary locations for BF R&D, production, and marketing. The Ukrainian-Japanese BCF production company was founded in 2000. The United States of America, Austria, China, South

Korea, and Japan are all developing BCF technology. European Union (EU) and other countries also have BF research initiatives.

Basalt, a type of dark, fine-grained, solidified volcanic rock, is the source of the BF found in nature. The word "basalt" can refer to several distinct varieties of volcanic rock. Although basalt is a hard, dense, and inert igneous rock formed when volcanic lava cooled, it melts at high temperatures like thermoplastics. Basalt is formed when lava cools rapidly in the open air following a volcanic eruption or a flood volcano. Lava originates as a very hot fluid or semi-fluid material deep within the Earth's crust. About 70% of Earth's surface is made up of basalt flows, the majority of which are composed of SiO2, followed by Al2O3, then Fe2O3, FeO, CaO, and MgO. Therefore, the SiO2 content of basalt rocks is used to categorise them as either alkaline (up to 42%), mildly acidic (43-46%) or acidic (more than 46%). Basalts of the acidic type are the only ones that can be processed into fibre. Glass network requires high silica content. The basalt rock shown in Figure 1.1 is fairly typical.

Figure 1.1 Basalt rock. Re-used with permission

2. LITERATURE REVIEW

Li, Z., Ma, J. et al,(2018) Basalt fibre is a high-tech fibre that doesn't pollute the environment and is healthy for humans and wildlife alike. It finds extensive application in both the military and civilian sectors. Theoretically and strategically, there is a great need for more investigation into the properties of basalt fibre and its composite materials. Mechanical strength, acid-alkali resistance, electrical conductivity, wave permeability, and insulation effectiveness are just some of the areas where basalt fibre is shown to excel. In light of these advantages, it seems likely that combining basalt fibres with a substrate can boost material performance. These features make

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basalt fibre and its composites suitable for use in the manufacture of heat and cold resistant clothing, as well as soundproofing and thermal insulation materials. Its unique qualities make it useful in a wide variety of non-industrial contexts.

Jamshaid, H., & Mishra, R. (2016) In the last century, new materials have been developed at such a rapid rate because demands for structures, automobiles, etc. are changing so rapidly. Engineers are constantly looking for ways to get better results from the materials already at their disposal, so they've come up with clever ways to combine materials to get effects that would be impossible with just one. Common metals, ceramics, and plastics aren't always up to the task of fulfilling the requirements of today's technologies, which often call for materials with unusual combinations of properties. This is especially the case for building supplies and transportation equipment. Metal alloys have long been the standard in many industries, but composites are quickly becoming a viable alternative in construction, transportation, marine, aerospace, and sports goods, among others.

Colombo, C., Vergani, L. A et al,(2012) Reinforced composites made from basalt are a newer material. For a fraction of the price of carbon fibres and with the same or greater strength as glass fibres, these mineral amorphous fibres are an attractive alternative. Mechanical characterization is required before basalt reinforced composites can be used in structural applications. In order to accomplish this, the present work details the experimental outcomes of a battery of static and fatigue tests. Vinylester and epoxy, two types of polymeric matrices, are considered to determine the effect each has on the metrics under study. In tandem with these mechanical tests, thermography is used to assess the specimens' thermal response to mechanical loads. This experimental method provides a means of precisely defining the local heating of composites under mechanical loading and observing its behaviour in the lab. The proposed conclusion draws particular attention to the basalt fibre composite's behaviour and makes comparisons between the mechanical properties of BFRP and those of composite materials made from glass and carbon fibres.

Wu, G., Wang, X. et al,(2015) This study reports the findings of an experimental analysis of the tensile loss of basalt fibres and epoxy-based composites when subjected to various corrosive environments. Carbon and glass fibre composites are the gold standard. Research into the impact of accelerated experimentation on the tensile properties of the material at 25C and 55C was conducted through tension tests, mass loss weighing, scanning electron microscope imaging, and energy spectrum analysis. Basalt fibres were found to have a high resistance to corrosion from water and salt, a moderate resistance to corrosion from acids, and a high susceptibility to degradation in alkaline solutions. The tensile strength of plastic composites reinforced with basalt fibres is significantly higher than that of basalt fibres themselves. Etching in salt, water, and alkaline solutions, as well as a shift in the chemical composites in an acid solution, all contribute to the deterioration of basalt fibres. Basalt FRP composites' fracture properties are determined not by the fibres themselves but by the corroded interfaces between the fibres and the resin.

Manikandan, V., Jappes, J. W. et al,(2012) Reinforcing agents made from natural fibres are now being considered as a viable alternative to glass fibres in composite materials. Natural fibres have many benefits over glass fibres, including being cheaper, lighter, stronger, less likely to break during processing, requiring less energy to produce, and being recyclable. Using natural fibres as reinforcement for polyester composite is an excellent eco-reusing technique because the fibres themselves are waste. There are two types of natural fibres: those that occur naturally and those that are synthetically produced using natural ingredients. The majority of reinforcing materials used in polymer composites today are made of glass fibre. The use of carbon fibre is common when high levels of accuracy and durability are required (e.g., space technology, the aircraft industry, military applications and sports). Carbon fibre has the potential to significantly reduce weight and increase strength, but its production costs are ten times those of glass fibre, and adhesion between carbon fibres and the matrix is more difficult to achieve. Due to their low cost, high biodegradability, and satisfactory strength properties, natural fibres like flax, sisal, coir, hemp, etc. are gaining popularity.

Khandelwal, S., & Rhee, K. Y. (2020) Reinforcing fibres and matrix characteristics in fiber-reinforced composites (FRCs) span a wide range, making FRCs a versatile engineering material. Depending on the intended use and the required mechanical strength, different fibres and matrices must be chosen for an FRC. Because of their widespread applications, polymer and cement composites have been the subject of extensive research aimed at optimising the fiber-matrix interface. Because of their smaller dimensions, fibres naturally have greater mechanical strength than bulk matrices. The matrix shields the fibres from the elements and provides the necessary alignment for them. The interfacial region is the interface between the fibre and the matrix in a fibre-reinforced composite. Under stress, a crack will widen until it reaches the interfacial area, where it will either stop growing or continue to grow until failure by fibre pullout or fibre fracture. Fibre-reinforced composites (FRCs) benefit mechanically from increased stress transfer from the matrix to the fibre due to strong interfacial adhesion, while FRCs with poor interfacial adhesion experience fibre pullout. Therefore, the performance of the composite is heavily dependent on the fiber-matrix interface.

Bhat, T., Chevali, V. et al,(2015) Basalt fibre reinforced polymer matrix composites are outperforming E-glass reinforced composites in certain applications. The fire structural resistance of a basalt fibre composite is evaluated using both experimental and theoretical methods, and the results are compared to those of an equivalent laminate reinforced with E-glass fibres. When both the basalt fibre composite and the glass fibre laminate were subjected to the same radiant heat flux, the former heated up more quickly and reached a higher temperature. Tensile structural survival of the basalt fibre composite was found to be wanting when compared to that of the glass fibre laminate when both were exposed to the same level of radiant heat flux. Because of the similar rates of thermal softening and decomposition of the polymer matrix and weakening of the fibre reinforcement under tensile stress, the two materials behaved similarly under this loading condition. Poorer fire resistance can be attributed to the basalt fibre composite's higher emissivity, which causes it to heat up more quickly in a fire.

Balaji, K. V., Shirvanimoghaddam, K. et al,(2020) In order to meet the performance, durability, and safety requirements of automotive systems while still complying with the regulations in place, sustainable fibre reinforced polymer composites for automobile structures are being sought. GFRP is frequently used in the front end modules and liftgate, but it can't be used in other, more demanding areas because of its subpar mechanical properties. Carbon fibre reinforced thermoplastic polymer composites (CFRP) have a lot of potential applications, such as bonnet, but their high cost prevents widespread use. Basalt fibre reinforced thermoplastic polymer composites (BFRP) are eco-friendly materials that sit between glass fibre reinforced polymer (GFRP) and carbon fibre reinforced polymer (CFRP) on the performance and cost scale (CFRP). The efficiency with which loads are transferred from the matrix to the fibre is what determines the BFRP's mechanical performance. Since untreated basalt fibres have poor adhesion to polymeric matrices, special treatments are required to improve performance. Some of the more important chemical treatments discussed in this article include matrix

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functionalization, silane treatment, functionalized nanomaterial coating, and plasma polymerization. Milling and plasma irradiation are among the physical processes discussed.

Matykiewicz, D., Barczewski, M et al,(2017) Here, we investigated how the addition of basalt powder to basalt fibre reinforced epoxy composites affected their thermo mechanical properties. Torsion mode dynamic mechanical thermal analysis. The material's mechanical quality was analysed using both the static tensile test and the Charpy impact strength technique. The thermo gravimetric analyses were performed in both inert and oxidising atmospheres to examine the thermal stability. The epoxy composites' results were enhanced in stiffness and thermal resistance when basalt fibres and powder were used together. Dynamic mechanical thermal analysis confirmed that the newly developed hybrid composites were more stable in the face of temperature swings than the control sample. High-quality products for a variety of industries require research into and the development of new materials with tailored properties. As a result, numerous research papers and projects in the building, automotive, and maritime sectors continue to focus on fibre reinforced composites.

Czigány, T., Vad, J., &Pölöskei, K. (2005) Basalt fibres' potential as reinforcing materials in a polypropylene (PP) matrix have been investigated. Carding in conjunction with needle punching has been used to combine the brittle basalt fibres with the PP fibres, and pressing has yielded the composite sheets. Mechanical specimens of SEN-T fracture have been cut from the sheets, and the sensitivity of the composites to crack propagation has been studied. Reinforcing has been shown to increase fracture toughness. The appearance of gravels at the ends of basalt fibres increased the composite's toughness in comparison to the matrix. The gravels are a direct result of the Junkers production method, it has been noted. Electron microscopy pictures have also confirmed the findings. The impact that shifting technological parameters can have on basalt fibre production is studied using a model developed for this purpose.

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3. MATERIALS METHODS

3.1. Composite materials

With the help of woven basalt fabric and vinyl ester resin, a basalt fibre composite was created for use in high temperature and fire structural testing. The manufacturer (Zhejiang GBF Fiber Co., Ltd.) plain woven the basalt fabric with 300 tex tows to an areal density of 350 g/ m2. Basalt fibres averaged 12.7 lm in diameter (standard deviation of 1.4 lm). In order to achieve the desired cross-ply fibre pattern, the basalt fabric was stacked with the warp tows aligned. With the help of vacuum bag resin infusion (VBRI), vinyl ester resin (SPV 1349 Nuplex Composites) was infused into the fabric while it was still at room temperature. It took two hours of post-curing at 80 degrees Celsius after the vinyl ester matrix had gelled and partially cured under ambient conditions (23 degrees Celsius, 50% relative humidity) after infusion. Using the ASTM D-3171 burn-off method, the percentage of fibre volume in the basalt composite was calculated to be 53%. An analogous glass fibre composite was used to evaluate the basalt composite's fire resistance. Plain woven E-glass fabric (800 g/m2) with an average fibre diameter of 12.2 lm was used to reinforce the composite (standard deviation of 1.5 lm). Basalt and E-glass fibres had comparable diameters (within 0.5 lm). Both the glass fibre composite and the basalt fibre composite were fabricated with the same vinyl ester resin, VBRI procedure, and curing conditions. The glass fibre laminate had a cross-ply fibre stacking sequence and a fibre volume content of 55%. Besides reinforcement, there was no discernible difference between basalt and glass fibre composites.

3.2. High temperature property testing of basalt fibre tows and composites

3.2.1. Mechanical testing of fibre tows

Basalt fibres' tensile properties were measured after being heated to determine how quickly they soften and lose strength. This information is used to better understand the fire tensile resistance of the basalt composite. As in the testing, the tows (300 tex) used to reinforce the polymer composite were present in the woven basalt fabric. The basalt tows were heated to temperatures between 150 and 650oC for up to two hours at a time. After the tows were cooled to 20 degrees Celsius, their residual tensile strength was measured. A basalt tow was subjected to a 150 mm gauge section load at an extension rate of 2 mm/min until failure, with the help of an Instron

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load cell with a 10 kN capacity (Model: 4501). Once heated, basalt tows' tensile strength measurements were extremely close to those taken at room temperature. Table 3.1 shows the residual failure stress of basalt tows after heating them to 20 degrees Celsius. For good measure, we also include a table with the basalt tows' in-situ, high-temperature failure stress.

Table 3.1 shows that the basalt tow strengths measured at high temperature and at 20oC after high temperature exposure are highly correlated (5%). High-temperature weakening of the basalt tow seems "locked-in" and unaffected by the gradual return to room temperature. To save time, the tensile strength of the tows was evaluated at 20 degrees Celsius after thermal treatment rather than at higher temperatures in situ. The tensile failure load of E-glass tows was calculated to be 280 tex after being subjected to the same heat treatment and testing conditions as the basalt tows. The E-glass tow was subjected to the same heat treatment as the basalt tows, albeit at different temperatures and for different amounts of time, and the residual tensile properties were evaluated at 20 degrees Celsius. The variation in the failure load was calculated by testing five tows of basalt and E-glass at 20oC under the same temperature and heating time conditions.

3.2.2. Mechanical testing of composites

Basalt and glass fibre composites' tensile properties were measured in a temperature range of -20 to +300oC. Tensile tests were performed using composite coupons that were 150 mm in length, 25 mm in width, and 4 mm in thickness, as specified by ASTM D3039. The basalt composite was made with 18 plies of woven fabric while the glass fibre composite had 7 plies of woven fabric to get the same thickness. Due to the basalt's thinner plies compared to the glass plies, more plies were needed to make a sandwich. Despite this difference, the fibre volume contents of the two composites were surprisingly similar. The tensile tests were performed on a 100 kN MTS machine at a loading rate of 2 mm/min. Basalt and glass fibre composites were loaded at varying temperatures in the 0 (warp) tow direction until failure occurred. Three samples were examined for their tensile properties at varying temperatures. Pressure grips were used to secure the tabbed ends of the tensile specimens to the MTS machine. The gauge region of the samples was where the failures occurred, never the tabbed region. Components subjected to fire-stability testing In order to evaluate the fire resistance of basalt and glass fibre composites, miniature fire structural tests were carried out. For this purpose, we will simulate a

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tensile load on a plate to see how the material responds. The tensile failure load of the basalt tows was measured at both 20 degrees Celsius after being exposed to high temperatures and in situ at high temperatures. The percentages indicate the failure load that has been lost since the initial (room temperature) failure.

“Table 3.1 Comparison of the tensile failure load of the basalt tows measured at 20ºC following elevated temperature exposure and measured in-situ at elevated temperature. The percent values give the residual failure load relative to the original (room temperature) failure load”.

Temperature	**Following heat exposure**	**During heat exposure**
150ºC	85 N(100%)	82.5 N(97%)
350ºC	78.2 N(92%)	79.1 N(93%)
450ºC	57.8 N(68%)	62.1 N(73%)

exposed to one-side constant radiant heat flux representative of a possible fire scenario. The procedure entails applying tensile stress to a rectangular composite specimen while simultaneously applying unsteady-state radiant heat to one side of the specimen. At a distance of 25 mm from the radiant heater, the composite sample was heated. Composite test samples were 600 millimetres in length, 50 millimetres in width, and 9 millimetres in thickness. Both the basalt and glass fibre composites were 42 plies thick, but for different reasons. Neither material differed significantly from the other in terms of the volume fraction of its fibres (0.53).

For the blaze structural test, the composite sample was loaded in a constant tensile stress of 20% to 80% of the failure stress at room temperature, in the 0oC fibre (or warp) direction. The average failure stress for the basalt fibre composite at 20 degrees Celsius was 460 MPa, while the average failure stress for the glass fibre composite was 470 MPa. A composite sample was cut into 100 mm lengths and subjected to constant tensile stress while being heated with an initial incident radiant heat flux of 25 or 50 kW/m2. Medtherm heat flux transducer was used for heat flux calibration and testing (Model No. 32-10SB-10-197- 21633). Stress rupture time was used to characterise the sample's ability to withstand the heat of a fire by subjecting it to constant stress and unilateral radiant heating until failure. In each heat flux and tensile stress condition, two samples were examined.

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4. RESULTS AND DISCUSSION

4.1. Thermal response of basalt composite to fire

Basalt and glass fibre composites' temperature increases when subjected to 25 and 50 kW/m2 of heat flux. The thermocouples were placed on the front (heat exposed) and back (room temperature) surfaces of the composites, and the temperatures were recorded. Midway through the composites' thickness, thermocouples were positioned to record their temperatures over time. Both composites were subjected to multiple tests, and there was a consistent temperature difference of less than 20 degrees Celsius across all of them. When the composites were subjected to a lower heat flux of 25 kW/m2, the temperature rose in an instable fashion before reaching a state of near-thermal equilibrium. There was no ignition of the basalt or the glass fibre composites when they were subjected to the 25 kW/m2 heat flux. Due to the front face being ignited at a temperature of roughly 675 degrees Celsius at the higher heat flux of 50 kW/m2, the surface temperature of the basalt fibre composite skyrocketed. However, despite being subjected to the same heat flux over an extended period of time, the glass fibre laminate did not catch fire.

The basalt fibre composite got hotter and more quickly than the glass fibre composite. The basalt fibre composite reached approximately 540 and 7000C when subjected to heat fluxes of 25 and 50 kW/m2, while the glass fibre composite only reached 430 and 6400C under the same conditions. The basalt fibre composite warmed up faster than the glass fibre composite because its emissivity is higher (e 0.92 at 200C). At room temperature, the emissivity values were measured experimentally using a thermal infrared camera. We were unable to determine whether or not the emissivity values changed with temperature because it was challenging to position the infrared camera directly in front of the composite samples during the fire structural testing. Because of its higher emissivity, the basalt fibre composite caught fire at a heat flux of 50 kW/m2 because its temperature and decomposition rate reached critical levels. When the rate of release of volatiles from decomposing matter reaches a critical level, the result is an explosion. The higher temperature at which the basalt fibre composite combusted upon exposure to 50 kW/m2 suggests that it decomposed faster and released more volatiles than the glass fibre laminate.

Basalt fibre composite experienced faster temperature rise in the middle and back faces than glass fibre laminate. Basalt fibres and E-glass fibres have nearly identical values for thermal conductivity (k) and specific heat capacity (Cp) (k = 0.031-0.038 W/m K; Cp = 860 J/kg K). This proves that the basalt fibre composite's elevated internal and back surface temperatures are not the result of increased heat conduction. Instead, the higher temperature at the hot surface caused by the higher emissivity of the basalt composite is primarily responsible for the quicker heat-up rate within the basalt composite.

The solid curves represent the calculated temperature increases at the surface and the centre of the composites. These temperatures were derived using the thermal model described in Section 3. Only once before has this model been employed, and that was to ascertain the melting point of glass fibre laminates. This method has not been used to predict the temperature of other fiber-polymer composites, such as basalt fibre laminates. Except for the brief period immediately following ignition, when the computed temperatures were too low, the measured temperatures and the calculated temperatures for the basalt fibre composite were in good agreement. The glass-fiberlaminate's predicted and observed temperatures are also in good agreement.

4.2. Mechanical response of basalt composite to fire

As a result of the uneven heating, the basalt and glass fibre composites gradually weakened until they broke under tensile stress. Figure 4.1 depicts the axial extension - heat exposure time response of materials during tensile fire structural tests on basalt and glass fibre composites. Deformation extension curves for high (80%) and low (20%) tensile stresses are shown for the composites that were heated unilaterally by radiant energy at heat fluxes of 25 and 50 kW/m2. Moreover, in Fig. 4.1, a schematic curve is presented to illustrate the main processes leading to the deformation of the two composites under combined tensile loading and one-sided heating. Initially, the extension increases in a quasi-linear fashion with increasing heating time, due to the combined effects of thermal expansion of the composite and thermal softening of the polymer matrix. Since the thermal expansion coefficient of basalt fibre is higher than that of E-glass fibre and since the matrix softening rate is higher due to the faster heating rate, the basalt fibre composite initially elongated at a faster rate than the glass fibre laminate. A critical temperature is reached in the extension curves of both composites, after which the extension

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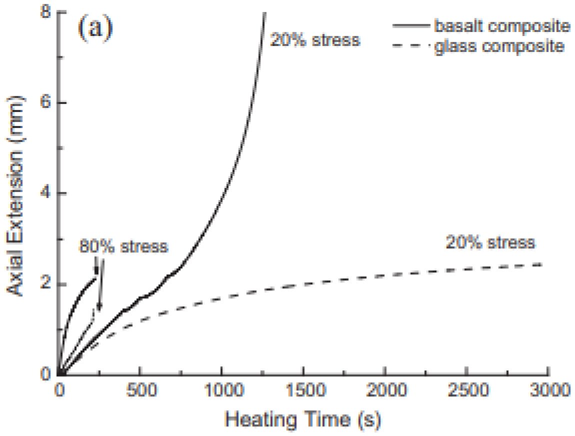
grows at a faster rate. When fibre/tow failures initiate near the heated surface, compliant composites are the result. Some of the fibres or tows fail before others when the composites are heated, causing a drastic increase in the extension rate. The basalt fibre composite fails progressively and more quickly, indicating that it has lower tensile structural fire resistance than the glass fibre composite.

Breakage times of basalt and glass fibre composites under 25 and 50 kW/m2 of heat flux are shown in Fig. 4.2, along with the effect of applied tensile stress. Rupture time is the amount of time a composite material can withstand a predetermined tensile stress before cracking under the influence of a given heat flux. As can be seen in the data points, the experimentally measured failure times increased for both composites as the applied stress and/or heat flux decreased. This suggests that the basalt composite has poor fire resistance under tensile loading, as its rupture times were significantly lower.



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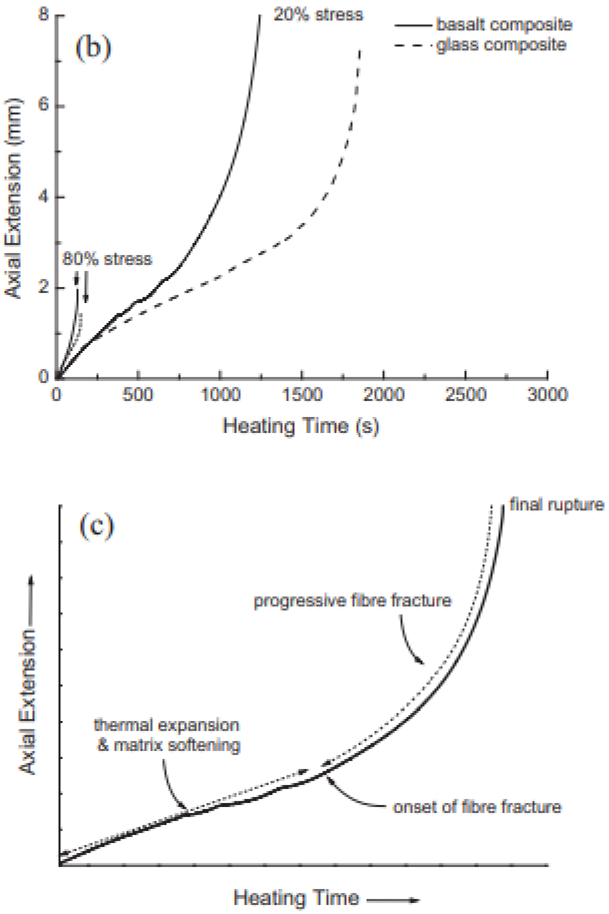

"Fig. 4.1 Effect of heating time on the axial extension of the basalt and glass fibre composites at the heat fluxes of (a) 25 and (b) 50 kW/m2 . The applied tensile stress values are expressed as a percentage of their room temperature tensile failure stress. (c) Schematic showing the softening processes occurring during tensile extension of composites".

For Fig. 4.2, the thermal-mechanical model was used to produce the curved lines. The model was initially developed to predict the tensile softening of glass fibre laminates in fire, but the excellent agreement between calculated and measured failure times for the basalt composites shows that it also works well with this material.

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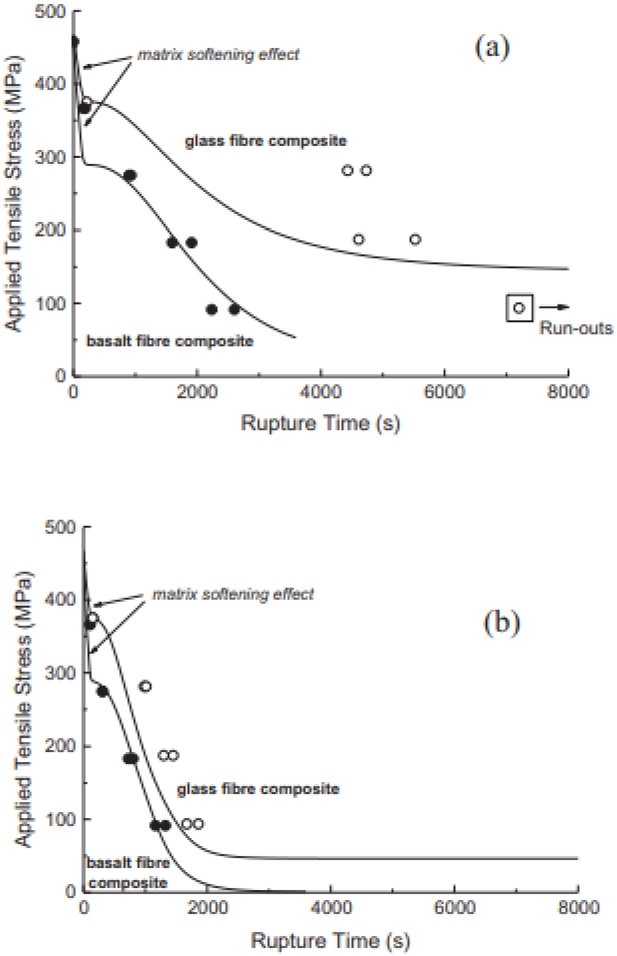

Fig. 4.2 Effect of constant tensile stress on the rupture times of the basalt and glass fibre composites when exposed to heat fluxes of (a) 25 and (b) 50 kW/m2 .

5. CONCLUSION

As a result of its high softening and melting temperatures and low thermal conductivity, basalt fibre is gaining popularity as a fireproof material. Compared to E-glass fibre, basalt fibre has a higher Young's modulus and tensile strength. A basalt fibre composite has been shown to have lower tensile fire resistance than an equivalent glass fibre laminate when both are exposed to the same heat flux indicative of a fire. Basalt and glass fibre composites softened and broke down at roughly the same rates when heated. On the other hand, due to its higher emissivity, the basalt fibre composite heated up faster and to higher temperatures. Since the basalt composite's

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polymer matrix and fibres softened and decomposed at a faster rate than those of the glass fibre composite when subjected to simultaneous tensile loading and unidirectional radiant heating, it had lower fire resistance than the glass fibre composite.

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