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MECHANICAL PERFORMANCE OF BASALT AND GLASS WOVEN COMPOSITES

BAZALT VE CAM TAKVİYELİ DOKUMA KOMPOZİTLERİN MEKANİK PERFORMANSI

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MECHANICAL PERFORMANCE OF BASALT AND GLASS WOVEN COMPOSITES

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ABSTRACT: This study systematically evaluates the mechanical properties of glass and basalt high-performance fibres in woven fabric-reinforced composites with thermoplastic and thermoset matrices. Investigating responses to diverse quasi-static and dynamic impact loads, the research emphasizes the growing interest in composites as alternatives to conventional metals. Examining basalt and glass fibres within different matrices, the study optimizes composite materials by scrutinizing tensile strength, flexural strength, and edge-wise impact resistance. Combining literature review and experiments, the research highlights basalt fibres for their high tensile strength and environmental sustainability. Key findings show that, under quasi-static conditions, thermoset composites excel in in-plane load bearing, while thermoplastic composites exhibit exceptional edge-wise impact resistance. Additionally, the study notes the superior flexural properties of thermoplastic-based basalt composites over glass, with dynamics shifting under thermoset matrices. This underscores the profound influence of both reinforcement and matrix materials on composite mechanical properties. Basalt thermoplastic composite outperforms glass-based counterpart in tensile properties, demonstrating superior elasticity and plasticity for enhanced deformation resistance. In flexural characteristics, basalt reinforced composites excels, displaying higher modulus, strength, and flexibility compared to Glass-based thermoplastic composite, highlighting the superior mechanical attributes of basalt composites. The Izod impact properties showcase basalt composites' exceptional resistance, with higher impact strength and energy values, surpassing glass counterparts. This underscores the potential of basalt-based materials for applications requiring superior resilience to dynamic impact loading.

Key words: Thermoplastic, thermoset, composites, basalt

BAZALT VE CAM TAKVİYELİ DOKUMA KOMPOZİTLERİN MEKANİK PERFORMANSI

ÖZ: Bu çalışma, termoplastik ve termoset matrisli dokuma kumaş takviyeli kompozitlerdeki yüksek performanslı cam ve bazalt liflerin mekanik özelliklerini sistematik olarak değerlendirmektedir. Çeşitli yarı statik ve dinamik darbe yüklerine verilen tepkileri araştıran araştırma, geleneksel metallere alternatif olarak kompozitlere olan ilginin arttığını vurgulamaktadır. Farklı matrislerdeki bazalt ve cam liflerin etkisinin incelendiği çalışmada, çekme mukavemetini, eğilme mukavemetini ve kenar darbe direncini özellikleri ele alınarak kompozit malzemeler optimize edilmiştir. Literatür taraması ve deneyleri birleştiren araştırma, bazalt liflerinin yüksek gerilme mukavemeti ve çevresel sürdürülebilirliği öne çıkarmaktadır. Temel bulgular, yarı statik koşullar altında, termoset kompozitlerin düzlem içi yük taşıma konusunda üstün olduğunu, termoplastik kompozitlerin ise olağanüstü kenar darbe direnci sergilediğini göstermektedir. Ek olarak çalışma, termoplastik bazlı bazalt kompozitlerin cama göre üstün eğimne özelliklerine ve termoset matrislerde ise dinamik kaymalara dikkat çekiyor. Bu durum, hem takviye hem de matris malzemelerinin kompozit mekanik özellikler üzerindeki derin etkisinin altını çizmektedir. Bazalt termoplastik kompozit, gerilme özelliklerinde cam bazlı muadilinden daha iyi performans göstererek, gelişmiş deformasyon direnci için üstün esneklik ve plastiklik sergilemiştir. Eğilme özellikleri açısından, bazalt takviyeli kompozitler üstündür; cam bazlı termoplastik kompozitle karşılaştırıldığında daha yüksek modül, güç ve esneklik sergiler ve bazalt kompozitlerin üstün mekanik özelliklerini vurgular. Izod darbe özellikleri, bazalt kompozitlerin olağanüstü direncini, daha yüksek darbe mukavemeti ve enerji değerleriyle cam muadillerini geride bıraktığını gösterir. Bu, bazalt bazlı malzemelerin dinamik darbeli yüklemeye karşı üstün dayanıklılık gerektiren uygulamalardaki potansiyelini vurgulamaktadır.

Anahtar kelimeler: Termoplastik, termoset, kompozitler, bazalt

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1. INTRODUCTION

In recent decades, fibre-reinforced composites have garnered significant attention in material science and practical applications due to their superior strength and stiffness-to-weight ratios compared to traditional materials such as metals. Fibre-reinforced polymer (FRP) composites, particularly those reinforced with glass fibres, have found extensive use in aerospace, automotive, and sports industries. These composites present appealing characteristics for civil engineering applications, including high performance, lightweight construction, and reduced lifecycle costs. Currently, FRPs are actively employed in retrofitting concrete and steel structures, seismic retrofitting of bridge piers, specialized applications for bridge decks, and internal reinforcement for concrete structures. The advantages of FRP encompass faster construction, increased strength, reduced weight, and enhanced environmental durability. However, challenges associated with FRP applications primarily revolve around maintenance and cost considerations [1]. Derived from volcanic rocks, basalt fibre has emerged as an environmentally friendly alternative, demonstrating not only cost-effectiveness but also superior mechanical properties when compared to glass fibres. Despite a common chemical composition, basalt Fibre outperforms in multiple facets, providing elevated tensile strength and modulus [2–5]. Furthermore, these fibres possess non-toxic and non-combustible attributes. This article aims to bridge a research gap by investigating the distinct impacts of basalt and glass fibres as reinforcement materials, thereby enriching the understanding of their mechanical behavior within woven composites.

The matrices used in composites can be divided into two main categories: thermoplastic and thermosetting polymers [6,7]. Thermoplastic polymers such as polypropylene (PP), polyamide (PA), and polycarbonate (PC) become fluid when heated to their melting temperatures. The material formed when these polymers are used as matrices in composites is known as a thermoplastic composite [8–11]. On the other hand, thermosetting polymers experience permanent hardening when exposed to heat, starting from a liquid prepolymer or resin. The hardening process of thermosetting polymers gives them unique properties such as high heat resistance and stiffness. Unlike thermoplastic polymers, they do not melt again once hardened [12–14]. These types of composites, which use thermosetting polymers as matrices, are called thermoset composites. They are widely used in aerospace applications due to their excellent toughness and heat resistance [15–17]. High performance fibre-based composites are normally fabricated from continuous fibre reinforcements embedded in a thermosetting resin[18–20]. Although thermoset composites offer excellent heat resistance and toughness, there is still a need for thermoplastic composites because of their ability to be produced quickly and easily fabricated. PP, renowned for its affordability and decent mechanical properties, is commonly used as a matrix in a range of composites [21]. The Glass Mat Thermoplastic (GMT) composite, which uses PP with a glass fibre (GF) mat, is a noteworthy example [22,23]. GMT composites often use short fibres in the matrix, with fibre content ranging from 20 to 40 wt% to enhance mechanical strengths and plasticity [24]. Nevertheless, despite these efforts, the mechanical strengths of GMT composites often do not meet industrial requirements [25]. To address this limitation and enhance the tensile and impact strengths of the composites, longer reinforcement fibres have been introduced into the thermoplastic matrix [18]. The length of these long glass fibres is approximately twice that of the short glass fibres traditionally used in GMT composites. Consequently, composites containing long glass fibres in the thermoplastic matrix exhibit superior mechanical strength and heat resistance [26,27]. Currently, thermoplastics are receiving considerable attention as matrix materials in structural composites. Fabricating structural composites is normally labor intensive and requires elaborate, lengthy cure cycles. By using thermoplastic matrices substantial reductions in forming time and labor are anticipated. Thermoplastic composites typically require a shorter and simpler processing cycle, as their processing mainly deals with heating and cooling of matrix material and involves no chemical reactions [28–30]. The high viscosity of thermoplastic resins presents difficulties in their use, especially when fully impregnating fibre preforms during production, despite the many benefits of these resins. Hybrid yarns, which combine the matrix and reinforcing elements, have been the subject of numerous studies that address this issue[31].

In recent years, basalt fibres have found application in various sectors, including the production of compressed natural gas (CNG) cylinders. These cylinders demand strength, lightweight properties, and resistance to impact and temperature. Typically constructed with metallic materials or lighter fibres reinforced by polymeric materials (FRP), the use of basalt fibre provides a viable alternative to carbon fibre due to their comparable durability and strength, coupled with the cost-effectiveness and availability of basalt fibres compared to carbon fibres [32]. Beyond this, basalt fibres, known for their excellent physical and mechanical properties, serve as effective reinforcing materials for concrete. Research by Li and Xu [33,34] has demonstrated a significant enhancement in deformation and energy absorption capacities of geopolymeric concrete through the addition of basalt fibres, although no notable improvement in dynamic compressive strength was observed. Exploring applications in transportation, Liu et al. conducted preliminary work [35] involving polymer composites reinforced by basalt fabric and glass fabrics. The produced composites underwent tensile, compressive, flexural, and shear tests, revealing a void content below 3% for all samples in the testing program. Remarkably, no significant differences were noted in Young's modulus, tensile strength, flexure strength, shear strength, and compression strength between basalt and glass composites. This versatility and comparable performance make basalt fibres a promising candidate in various engineering applications. The increased adoption of basalt Fibre in various applications, driven by its eco-friendly characteristics, positions it as a prospective material for future use. Basalt fibre demonstrates favorable attributes, including low cost and superior mechanical properties such as strength and modulus, when compared to glass fibres. Despite sharing a similar chemical composition, basalt fibre consistently outperforms glass fibres across a range of properties [4,5,36,37]. This inorganic fibre exhibits high tensile and compressive strength, modulus, as well as excellent chemical and thermal stability. Moreover, it showcases desirable electrical and sound insulation properties [35,38]. Notably, basalt fibre is non-toxic and non-combustible, adding to its appeal [39,40]. However, it is important to note that despite these advantages, basalt fibres exhibit poor impact properties due to their inherently brittle nature [41].

The surge in interest in natural fibres is attributable to their inherent qualities and widespread availability in comparison to synthetic fibres. Glass, renowned for its lightweight, strength, and durability, plays a pivotal role in various applications. Despite not matching the strength of high-performance fibres, the cost-effectiveness of glass positions it as a compelling alternative [25]. However, challenges persist in the carbon Fibre-based composite industry, stemming from production costs and susceptibility to stress concentrations due to carbon fibres' brittleness [26]. In contrast, basalt emerges with excellent inherent load-bearing properties. Building on insights from prior literature, this study aims to investigate the impact of reinforcement and matrices in two-dimensional woven composites under various strain rate conditions—both quasi-static and dynamic. Two-dimensional woven preforms with consistent areal density were crafted using 1200 tex linear density E-glass and basalt. Vacuum-assisted resin transfer method (VARTM) was employed for formulating thermoset composites with an epoxy matrix. Conversely, innovative hybrid reinforcements enveloping polypropylene (PP) around a reinforcement core were developed for thermoplastic composites. These reinforcements were used in woven preform fabrication, and the compression molding method produced 2D woven thermoplastic composites. This study thoroughly examines the mechanical behavior of thermoset and thermoplastic resins, with a specific focus on various fibre varieties. Comprehensive mechanical property analyses, including dynamic impact tests (drop-weight impact and Izod impact) and quasi-static tests (tensile and flexural tests), were conducted to fully characterize these composites. By shedding light on the nuanced mechanical behavior of these composites, the study significantly contributes to the ongoing advancement of composite materials technology. It lends crucial support to the development of innovative and environmentally friendly solutions across diverse industries.

While numerous studies have explored the mechanical properties of woven fabric reinforced polymer composites over the past decades, the present research offers a novel contribution by focusing on the compatibility between distinct combinations of matrix materials and fibres. By investigating the mechanical behavior of basalt and E-glass thermoplastic and thermoset composites within the same experimental framework, the study aims to provide valuable insights into the performance characteristics and potential applications of these materials.

2. MATERIALS and METHODS

2.1. Materials

Basalt and E-Glass roving were obtained from Arrow Technical Textiles Mumbai and Owen's Corning respectively, each having a linear density of 1200 tex. Table 1 provides a comprehensive breakdown of the properties of those reinforcement fibres. The matrix fibre utilized for crafting hybrid reinforcements and developing hybrid dry-woven fabrics was Polypropylene (PP) multifilament, sourced from Fitpack Textile Mills Ltd. The thermoset resin, Lapox ARL-125 epoxy, and its hardener, AH-367 curing agent, were sourced from Atul Pvt. Ltd.. The properties of the PP matrix material can be found in Table 2, while Table 3 provides the properties of the thermoset resin and its hardener.

Table 1: Mechanical properties of reinforcement fibres

Fibre	Linear Density [Tex]	Density [g/cm3]	Tensile Strength (GPa)	Tensile Modulus (GPa)	Elongation at break (%)
Basalt	1200	2.8	2.8	80-90	3.15
Glass	1200	2.56	1.4-2.5	65-72	1.8-3.2

Table 2: Mechanical properties of polypropylene multifilament

Description	Polypropylene
Linear density (Denier)	840
Density (g/cm^3)	0.91
Tensile strength (MPa)	75
Melt flow index (g/10min)	35
Melting temperature (˚C)	160

Table 3: Properties of epoxy resin and compatible hardener

Description	Unit	Lapox ARL-125 epoxy	AH-367 curing agent
Appearance	Visual	Clear liquid	Clear liquid
Composition	-	Epoxy resin	Modified polyamine
Viscosity	mPa.s	1000-1500	10-50
Density	gm/cc	1.15	0.93-0.99

2.2. Methods

2.2.1 Preparation of the reinforcement/ PP hybrid yarns

Hybrid yarns of reinforcement (E-Glass and Basalt) and PP were produced using the co-wrapping method within a wrap spinning technique. The manufacturing process employed a hollow spindle spinning machine. The reinforcement roving went through a roving condenser and in-active drafting rollers, as the linear density was already fixed. This core roving, devoid of true twist, was directed into the hollow spindle. Concurrently, PP filament from a package mounted on the hollow spindle traversed through the hollow spindle. Consequently, the PP filament strand was wrapped around the reinforcement at the core. The high rotational speed of the spindle imparted pseudo-twist to both the reinforcement and PP filament. Upon passing through the twisting hook, the false twist in the E-Glass roving untwisted, while the PP filament wraps retained their twist, as shown in figure 1. To maintain a consistent Fibre volume fraction of 50% ± 5%, this process was meticulously executed. The selection of polypropylene as the thermoplastic polymer and its specific volumetric ratio of 50% within the composite material are based on a comprehensive evaluation of mechanical, chemical, economic, and processing factors, aiming to achieve an optimal balance of performance and cost-effectiveness for the intended applications.

2.2.2 Preparation of two-dimensional (2D) woven fabrics

2D woven fabrics with plain weave design were developed on the customized rapier weaving loom at Focus Incubation Centre at Indian Institute of Technology Delhi. Ends per inch and picks per inch were calculated in a way so that constant areal density can be achieved. Areal densities of glass and basalt fabrics were 593gm/m^2 and 611 gm/m^2 respectively. Later, 4 layers of 2D wove fabrics with areal density aprox. 2400 gm/m^2 were laid one after another in 0-90^0 sequence.

2.2.3 Development of thermoplastic composites

The thermoplastic composites were fabricated through the compression molding technique. Utilizing their corresponding 2D woven preforms, thermoplastic composites incorporating E-Glass/Polypropylene and Basalt/Polypropylene were developed, which are named as TPG2DFRC, and TPB2DFRC respectively. The 2D woven preform was positioned within the mold, enveloped with Teflon sheets at both the top and bottom, and underwent processing in a compression molding machine. The processing conditions entailed exposing the composites to a temperature of 185°C and 10 bar pressure for duration of 10 minutes during full press heating and an additional 10 minutes for cooling, as illustrated in Figure 2.

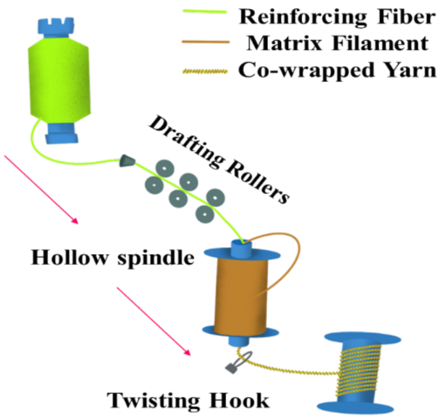

Figure 1: Manufacturing process of Hybrid Reinforcement by Wrap Spinning

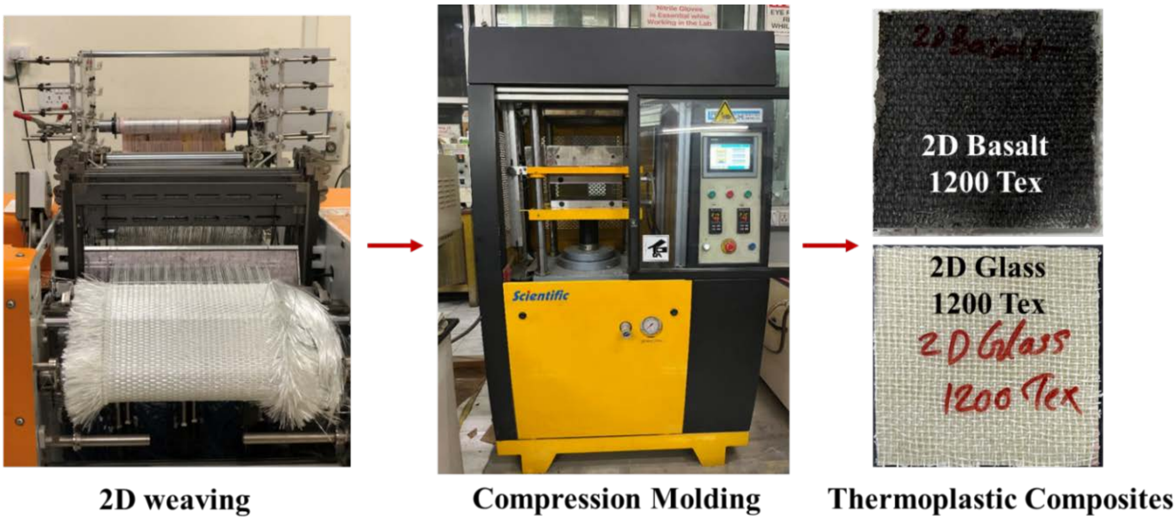

Figure 2: Manufacturing process of 2D woven fabric-based thermoplastic composites

2.2.4 Manufacturing of thermoset composites

The production process for 2D woven fabric-reinforced composites (2DFRCs) utilizing 2D weaving preforms employed vacuum-assisted resin transfer molding (VARTM). To achieve optimal results, a resin-to-hardener ratio of 100:32 was determined through mechanical attribute optimization, using the same resin material. The resin-hardener mixture underwent de-airing in a desiccator, involving two two-minute cycles to eliminate any air bubbles before impregnation. The VARTM process, illustrated in Figure 3, outlines the steps involved in producing 2DFRCs. Subsequently, the samples underwent a vacuum application at a pressure of -1 kg/cm2, curing for 24 hours at 25°C post resin infusion, following the manufacturer's instructions to attain a high level of handling strength. Upon completion of the initial curing for 2D woven composites, a post-curing process was initiated at 80°C for 2 hours to ensure the composite characteristics met the highest quality standards.

Following equation was used to determine composite FVF:

$$\text{FVF\%} = \frac{\frac{Fabric\ weight}{Fiber\ density}}{\frac{Fabric\ weight}{Fiber\ density} + \frac{Resin\ weight}{Resin\ density}} \times 100$$

In this equation, FVF% was kept at 50%. Accordingly, the value of resin weight was measured to prepare the composites and achieved the constant FVF% value.

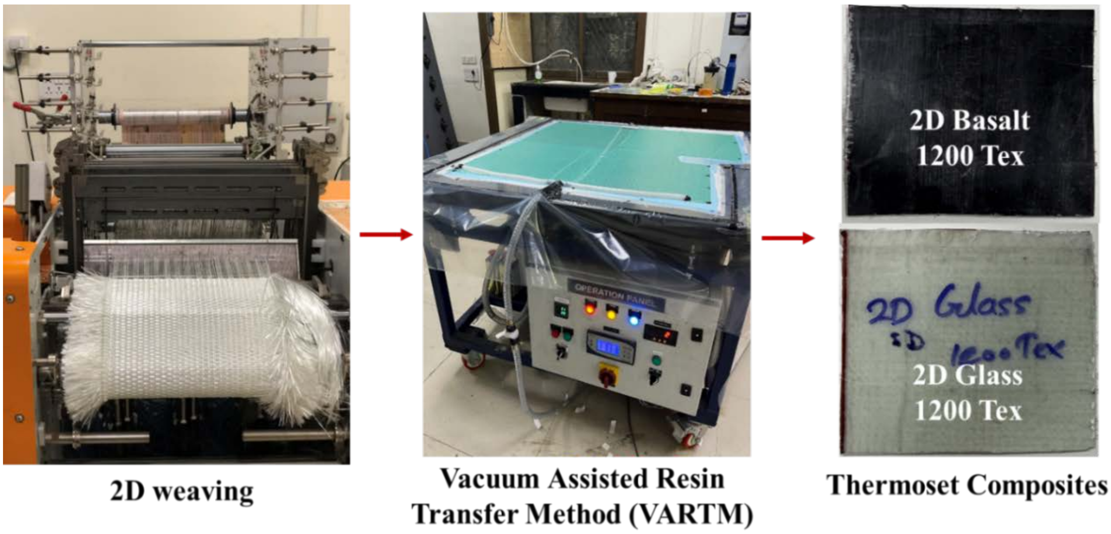

Figure 3: Manufacturing process of 2D woven fabric-based thermoset composites

2.2.5 Characterization of mechanical properties of 2D woven structural composites

2.2.5.1 Tensile test

The tensile testing was carried out using Zwick Roell Z250 UTM with ASTM D3039 standard. The test speed kept was 2 mm/min. Force shutdown threshold was 80% of $F_{max.}$ Load-cell used was 250kN and sample size was 200 mm X 25 mm. Upper force limit was 100 kN and gauge length was 100 mm. Gripping attachment was pneumatic in nature.

2.2.5.2 Flexural (3-point bending) test

The flexural testing was carried out using Zwick Roell Z250 UTM with the ASTM D7264 standard. The test speed kept was 2 mm/min. Force shutdown threshold was 80% of F_{max}. The load-cell used was 25kN and span to thickness ratio was 32:1. Upper force limit was 100 kN and specimen width was 13 mm. Gripping attachment was pneumatic in nature.

2.2.5.3 Edgewise impact test

The edgewise impact test was carried out using Izod Impact (Pendulum type) instrument with ASTM D256 standard. The impact velocity kept was 3.5 m/sec. Pendulum energy and mass was 11 Joule and 1.84 kg respectively. The angle of release was 147.96^0. Sample size was 64 mm X 12.7 mm. Notch-depth length was 2 mm and notch angle was 45^0.

2.2.5.4 Drop-weight impact test

A calibrated INSTRON CEAST 9350 instrument with a 22.4 kN load-cell capacity performed the drop-weight impact test with ASTM D7136 standard, a common drop-weight impact assessment method. A weight-free-falling, anti-rebound technology prevented several strikes in the testing system. A 12.7 mm-diameter, 10.4390-kg hemispherical steel impactor was dropped without friction from 503 mm at 3.14 m/s with nominal impact energy of 50J. The study tested damage resistance, the material’s ability to absorb blows before perforation, and a rebound mechanism to prevent repeated collisions. The software was used to analyze the composite specimen’s impact reaction as a time-dependent force, displacement, and energy function.

3 RESULTS AND DISCUSSION

3.1 Tensile behavior of thermoplastic and thermoset woven composites

Initially, TPG2DFRC displayed a higher tensile modulus in the elastic regime compared to TPB2DFRC . The elastic regime refers to the initial phase where the material deforms reversibly under stress. TPG2DFRC maintained its superiority until around 4% strain, which indicates the percentage increase in length of the material under the applied stress. However, at approximately 4% strain, a slight deviation occurred in the behavior of TPG2DFRC, and both curves entered the hardening phase. In the hardening phase, the strain continued to increase beyond 10%, but at a slower pace compared to the elastic range, eventually reaching a maximum of 12.5%. The strain failure, where the material ultimately breaks, occurred at 18%. This behavior suggests that TPG2DFRC exhibited a combination of elasticity and some degree of plasticity before reaching failure. In contrast, TPB2DFRC demonstrated enhanced performance beyond the elastic regime. Thermoset composites generally exhibit a lower strain percentage before failure due to their brittle nature, meaning they undergo minimal deformation before breaking. In this case, TPB2DFRC displayed a lower strain percentage compared to TPG2DFRC. The results also indicate that basalt Fibres showed a relatively better load-bearing ability than glass Fibres in this context. This observation could be due to the specific mechanical properties of basalt Fibres, which may include higher stiffness and strength compared to glass Fibres in the given composite system.

The superior load-bearing performance of the thermoset composites (TSB2DFRC and TSG2DFRC) is attributed to increased interphase bonding and stiffness with the matrix than the thermoplastic. In composite materials, the interphase is the region between the Fibre and the matrix where bonding occurs. Improved interphase bonding enhances stress transfer between the Fibre and matrix, contributing to better load-bearing capacity along the longitudinal axis of the composite material.

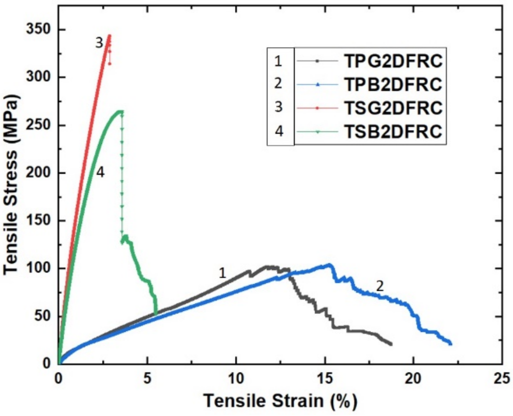

Figure 4: Stress and strain graph of thermoplastic and thermoset woven composites

Figure 5: Tensile tested specimens at 2mm/min strain rate

Table 4: Tensile properties of Glass and Basalt based 2D woven thermoplastic and thermoset composites

Specimen ID	Tensile Modulus MPa	Tensile Strength MPa	Tensile Stress at Break MPa	Tensile Strain at Break, e_B %	Thickness, h mm	Width, b mm	Cross-sectional Area, A_0 mm^2
TPG2DFRC	2077.93	102.09	20.40	18.75	5.60	25	140
TPB2DFRC	1885.92	103.72	20.57	22.07	6.60	25	165
TSG2DFRC	18299.96	343.61	314.21	2.88	2.10	25	52.50
TSB2DFRC	14226.84	264.69	52.16	5.47	2.50	25	62.50

3.2 Flexural behavior of thermoplastic and thermoset woven composites

In the realm of flexural properties, the Basalt-based thermoplastic composite (TPB2DFRC) emerges as a standout performer. It boasts a notably higher flexural modulus in comparison to its Glass-based thermoplastic counterpart (TPG2DFRC), indicative of its superior stiffness and heightened resistance to deformation when subjected to flexural stress. This heightened stiffness is complemented by TPB2DFRC's superior flexural strength, signifying its ability to endure more substantial bending forces before succumbing to failure. Moreover, TPB2DFRC distinguishes itself by displaying a greater flexure strain at break when contrasted with TPG2DFRC. This outcome underscores the Basalt composite's enhanced flexibility and ductility, implying its capacity to undergo more significant deformation before reaching the breaking point. The robust mechanical performance of Basalt in the thermoplastic domain sets the stage for a nuanced comparison with its thermoset counterparts.

Transitioning to thermoset composites, the Glass-based thermoset composite (TSG2DFRC) exhibits markedly higher values for both flexural modulus and flexural strength when compared to its thermoplastic counterpart (TPG2DFRC). This indicates a significantly stiffer and stronger response to flexural loading, a characteristic inherent to thermoset materials. Furthermore, TSG2DFRC demonstrates a higher flexural stress at break and a lower flexure-strain at break in comparison to TPG2DFRC, suggesting that the thermoset composite can withstand more stress before breaking, albeit with less deformation. Parallel observations are mirrored in the Basalt-based thermoset composite (TSB2DFRC) in relation to its thermoplastic counterpart (TPB2DFRC). TSB2DFRC exhibits superior values for both flexural modulus and flexural strength, emphasizing its heightened stiffness and strength under flexural loading. Like the Glass composites, TSB2DFRC presents a higher flexural stress at break and a lower flexure-strain at break, aligning with the characteristic behavior of thermoset materials. A broader perspective reveals that thermoset composites, both Glass-based and Basalt-based (TSG2DFRC and TSB2DFRC, respectively), outshine their thermoplastic counterparts (TPG2DFRC and TPB2DFRC) in terms of flexural properties, particularly in tension mode. This collective set of observations affirms the superior mechanical attributes of Basalt-based composites across both thermoplastic and thermoset categories when compared to their Glass-based counterparts. These findings provide valuable insights into the nuanced interplay of matrix types and reinforcement materials, offering a comprehensive understanding of their mechanical behaviours in flexural loading conditions.

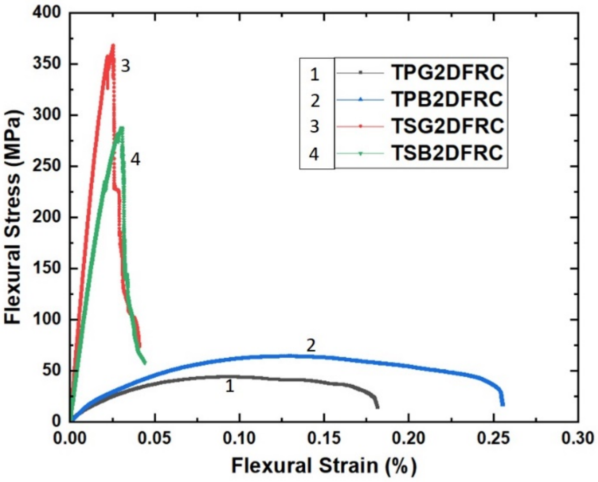

Figure 6: Flexural stress and strain graph of thermoplastic and thermoset woven composites

3.3 Izod impact behavior of thermoplastic and thermoset woven composites

The Izod (in-plane pendulum) impact properties of Glass and Basalt-based thermoplastic and thermoset composites, as indicated by the impact strength and impact energy per notch length, provide insights into their respective performance under impact loading conditions. The pendulum impact resistance observed in thermoplastic woven composites, such as TPG2DFRC and TPB2DFRC, can be attributed to their unique mechanical behaviour characterized by a capacity to deform and absorb energy through plastic deformation. Thermoplastics, with their distinct molecular structure, possess the ability to undergo plastic deformation. This allows them to absorb and dissipate energy by rearranging their molecules without undergoing permanent chemical changes. This plastic deformation mechanism contributes to their superior impact resistance compared to typically more brittle thermoset counterparts.

On the other hand, thermoset woven composites, exemplified by TSG2DFRC and TSB2DFRC, generally exhibit lower impact resistance due to their cross-linked and rigid molecular structures. This structural rigidity renders them more brittle, increasing the likelihood of catastrophic failure characterized by crack propagation and fragmentations upon impact. Comparing Basalt and Glass-based composites, Basalt composites show better impact resistance, as indicated by higher impact strength and impact energy values. This improved performance can be attributed to the superior tensile properties of Basalt, which outperform Glass yarns. The enhanced tensile properties contribute to better energy absorption and dissipation, resulting in superior impact resistance for Basalt composites. In summary, the Izod impact test results highlight the unique mechanical behavior of thermoplastic woven composites, emphasizing their ability to undergo plastic deformation and absorb impact energy. Additionally, the superior impact resistance of Basalt composites over Glass counterparts underscores the influence of the reinforcement material's tensile properties on overall impact performance.

Table 5: Flexural properties of Glass and Basalt based 2D woven thermoplastic and thermoset composites

Specimen ID	**Flexural Modulus, E_f**	**Flexural Strength, s_{fM}**	**Flexural Stress at Break, s_{fB}**	**Flexure Strain at Break, e_{fB}**	**Specimen thickness, h**	**Specimen width, b**	**Cross-section Area, A_0**
	MPa	**MPa**	**MPa**	**%**	**mm**	**mm**	**mm²**
TPG2DFRC	2136.73	44.04	14.09	18.18	5.60	13	72.80
TPB2DFRC	2242.22	63.93	16.67	25.55	6.60	13	85.80
TSG2DFRC	20454.18	368.47	73.67	4.10	2.10	13	27.30
TSB2DFRC	13216.37	287.82	57.56	4.40	2.50	13	32.50

TPB2DFRC **TPG2DFRC** **TSB2DFRC** **TSG2DFRC**

Figure 7: Flexural tested specimens at 2mm/min strain rate

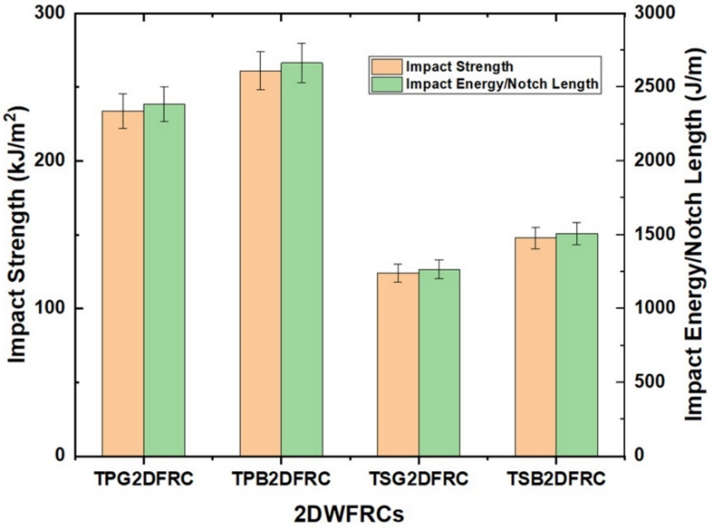

Figure 8: Izod impact properties of thermoplastic and thermoset woven composites

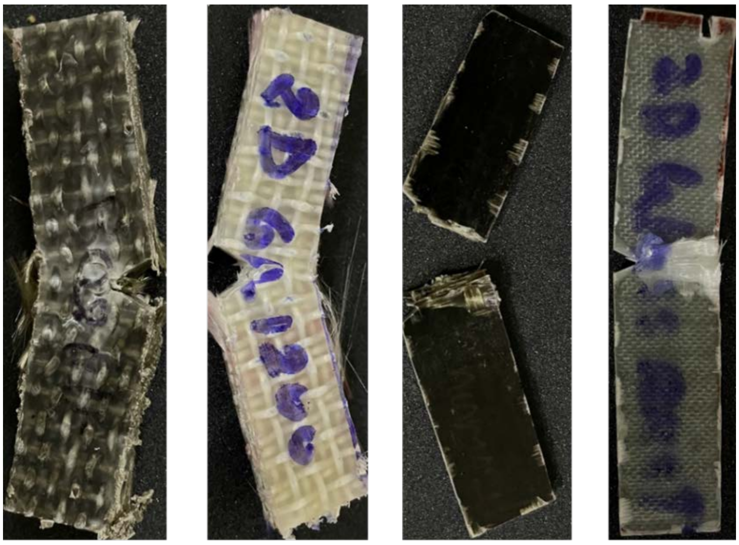

Figure 9: Izod pendulum impact tested specimens

4. CONCLUSIONS

In conclusion, this research has provided a comprehensive examination of the mechanical characteristics of basalt and glass reinforced composites, shedding light on the nuanced interplay between matrix properties and performance. Thermoset composites exhibited exceptional quasi-static mechanical performance, attributed to their crosslinked structure, providing superior stiffness and dimensional stability. In contrast, thermoplastic composites showcased remarkable resilience in edgewise dynamic impact properties due to their superior ductility and toughness. Basalt-based structures outperformed glass counterparts, showcasing elevated tensile strength. The tensile behavior of thermoplastic composites, exemplified by TPG2DFRC, displayed a combination of elasticity and some degree of plasticity, while TPB2DFRC demonstrated enhanced performance beyond the elastic regime. In the realm of flexural properties, TPB2DFRC emerged as a standout performer, demonstrating superior stiffness, strength, and flexibility compared to its glass counterpart. Thermoset composites, both glass-based and basalt-based, outshone their thermoplastic counterparts in terms of flexural properties, showcasing heightened stiffness and strength in tension mode. The Izod impact properties emphasized the unique mechanical behavior of thermoplastic woven composites, with superior impact resistance attributed to their capacity for plastic deformation. Thermoset composites exhibited lower impact resistance due to their cross-linked and rigid structures. Notably, Basalt composites demonstrated superior impact resistance over glass counterparts, underscoring the influence of reinforcement material tensile properties. In summary, this research contributes valuable insights into the intricate relationship between matrix types and reinforcement materials, offering a comprehensive understanding of their mechanical behaviors across various loading conditions. The superior mechanical attributes of basalt-based composites, especially in terms of tensile strength, flexural properties, and impact resistance, position them as promising materials for advanced engineering applications. These composites are suitable for various structural applications like Aerospace, Wind Energy, Automotive, Marine Industry etc.

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