Characterization of hair-sisal-glass fibre polyester hybrid composite materials

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Érkezett: 2024. 04. 25. ▪ Received: 25. 04. 2024. ▪ https://doi.org/10.14382/epitoanyag-jsbcm.2025.1

Abstract

This study investigates the mechanical properties of Hair/Sisal/Glass Fiber Reinforced Polyester plastic (HSGFRP) hybrid composites composed of 15% fiber content by weight, with equal proportions of hair, sisal, and glass fibers, and 85% polyester matrix. However, to ensure accuracy in representing the material composition, the fiber content was recalculated and expressed in terms of volume fraction (vol%), considering the differences in densities among the fibers and the matrix material. Based on this adjustment, the total fiber content corresponds to approximately 7.67% by volume, with equal volumetric proportions of hair, sisal, and glass fibers. Specimens fabricated using the hand lay-up technique were tested for tensile, flexural, impact, and water absorption properties. The HSGFRP achieved 53% of the tensile strength, 94% of the flexural strength, and 77% of the impact strength of Glass Fiber Reinforced Composite (GFRP), with moderate water absorption properties comparable to glass and glass/sisal fiber materials. The addition of glass fiber enhanced tensile and flexural strength while reducing impact strength. HSGFRP exhibits balanced mechanical properties, making it a viable, lightweight, and cost-effective alternative to traditional glass fiber composites for light-load applications, despite a noticeable gap in tensile strength compared to GFRP.
Keywords: hair fibre, hair/sisal fibre, hair/sisal/glass fibre, polyester hybrid plastics
Kulcsszavak: hajszál, haj/szizál szál, haj/szizál/üvegszál, poliészter hybrid műanyagok

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1. Introduction

The hybridization of natural and synthetic fibers has gained significant attention in recent years due to its potential to enhance the mechanical properties of composite materials while reducing both costs and environmental impact. Chemical treatments, such as alkaline and acrylic acid treatments, have been shown to further improve the mechanical properties of natural fiber-reinforced plastics, including tensile, flexural, and impact strength, as well as water resistance [1, 2].

Various composite materials have emerged by combining natural, synthetic, and hybrid fibres. Glass fibre, a widely used synthetic option, is known for its excellent mechanical properties, including tensile strength, stiffness, and impact resistance, making it versatile for engineering applications. Hybridizing glass fibre with natural fibres like sisal enhances the strength, particularly in impact resistance. However, factors such as impurities and volume percentage of reinforcements can affect mechanical properties [3-6].

Hair fibre, an underutilized natural option, shows promise in reinforcing composites, improving properties like compressive and bending strength, as well as water uptake. It has been explored for specific applications like engine piston materials, displaying notable resistance to creep, stiffness, and temperature [7-9].

Similarly, sisal fibre has been extensively used as a reinforcement, with studies focusing on fibre treatment effects on tensile strength, flexural strength, and water resistance. Evaluations at different fibre loadings reveal varied impacts on ductility, stiffness, and hardness [10-14].

This study aims to compare the mechanical properties of hair, sisal, and glass fibre-reinforced plastics, along with hybrid combinations. By analyzing the mechanical behaviors of these materials, the goal is to identify the most effective reinforcement combinations to improve their performance in engineering applications.

2. Materials and methods

2.1 Materials used

Hair fibre: Is collected from a local barber shop. It is washed with water and sun dried to free it from its oil and dusts content before treatment. Next it is soaked with 5% alkaline (NaOH) for twenty-four hours to improve their hydrophilic nature and sun dried again. Lastly, short fibres weighted based on their percentage and distributed evenly to form a lamina of hair fibre.

Sisal fibre: Is extracted from the sisal plant from local farm manually. Sisal fibre is then washed with water and sun dried to free it from its oil and dusts content. And it is soaked with 5% alkaline (NaOH) for twenty-four hours to improve their hydrophilic nature and sun dried again. At the end dried sisal fibre is chopped and layer is formed with randomly distributing the short fibres.

Glass fibre: is bought from the local market of water proof work Addis Ababa Ethiopia. Then weighted and in the form of layer to fit the Mold size.

Polyester resin: The type of polymer used in the recent research is a general-purpose unsaturated polyester known as TOPAZ-1110 TP which is collected from local fiberglass water proof manufacturing.

Fibers	Tensile modulus (E) (GPa)	Tensile strength (σ) (MPa)	Density (ρ) (g/cm³)
E – glass	69	2400	2.54
Hair	1.74 – 4.39	380 - 400	1.32
Sisal	9.4 – 22	400 - 700	1.45
Resin (Polyester)	2.0 – 4.5	40 - 90	1.3

Table 1 Mechanical properties of the constituent materials
1. táblázat Összetevők mechanikai tulajdonságai

Hardener (Methyl-Ethyl-Ketone-Peroxide) (MEKP): The Hardener is the second part of the matrix which is mixed with polyester resin to facilitate the curing of the resulted composite materials.

a) Sisal fiber *b) Hair fiber*
c) Glass fiber *d) Resin and hardener*
e) NaOH *f) Distilled water*

Fig.1 Materials used for composite preparation
1. ábra Kompozit készítéshez alkalmazott anyagok

2.2 Preferred fibre to matrix weight percentage

The composite materials were prepared with a fiber-to-matrix ratio of 15% and 85% by weight, respectively, based on the observation that the sisal-hair fiber reinforced composite exhibits maximum tensile, flexural, and impact strengths at this ratio. This weight percentage was initially chosen for consistency across all cases. However, expressing fiber content solely in terms of weight percentage is less accurate due to differences in densities between the fibers and the matrix material. To ensure scientific accuracy, the fiber content was recalculated and expressed in terms of volume fraction (vol%), where a 15% fiber content by weight corresponds to a total fiber volume fraction of approximately 7.67% [15]. This fixed fiber volume fraction was maintained across all configurations while varying the types of fibers to enable meaningful comparisons of mechanical properties. Eight distinct fiber-reinforced composite configurations were developed, including fully glass fiber, fully sisal fiber, fully hair fiber, glass and hair fibers, glass and sisal fibers, hair and sisal fibers, and a hybrid composite consisting of glass, hair, and sisal fibers. This adjustment ensures a more precise comparative investigation of mechanical properties while maintaining a constant total fiber volume fraction of 7.67% across all cases.

2.3 Volume, mass fraction and density of the samples

This research incorporates three types of fibres - hair, sisal, and glass fibre individually and in hybrid combinations, within a polyester thermosetting polymer matrix. Seven distinct composite types are developed by combining these fibres: glass fibre reinforced plastics (GFRP), sisal fibre reinforced plastics (SFRP), hair fibre reinforced plastics (HFRP), hair/sisal fibre reinforced plastics (HSFRP), hair/glass fibre reinforced plastics (HGFRP), sisal/glass reinforced plastics (SGFRP), and hair/sisal/glass fibre reinforced plastics (HSGFRP). Each composite type undergoes the preparation of five trial samples per tests and each result is recorded.
Where:

$\upsilon_{C,f,m}$	Volume of composite, fiber and matrix respectively
$\rho_{c,f,m}$	Density of composite, fiber and matrix respectively
$m_{c,f,m}$	Mass of composite, fiber and matrix respectively
$\rho_{f1,2,3...n}$	Density of the first, the second, the third and the nth fiber respectively
$m_{f1,2,3...n}$	Weight fraction of the first, the second and the nth fiber respectively
W_m, ρ_m	Weight fraction and density of the matrix respectively
W_f, ρ_f	Weight fraction and density of the fiber respectively

The fiber Volume fraction (V_f) and the matrix volume fraction (V_m) can be calculated,

$$V_f = \frac{\upsilon_f}{\upsilon_C} \text{ and } V_m = \frac{\upsilon_m}{\upsilon_c} \quad (1)$$

Volume fraction of fiber and matrix can also be related as,

$$V_f + V_m = 1 \text{ and } \upsilon_f + \upsilon_m = \upsilon_c \quad (2)$$

Weight fraction of fiber (W_f) and the matrix (W_m) are formulated as below,

$$W_f = \frac{m_f}{m_C} \text{ and } W_m = \frac{m_m}{m_c} \quad (3)$$

And similarly, the weight fraction of fiber and matrix can be related by,

$$W_f + W_m = 1 \text{ and } m_f + m_m = m_c \quad (4)$$

From density of a material weight or mass of the corresponding material is given by,

$$m_c = \rho_c * \upsilon_c, m_f = \rho_f * \upsilon_f \text{ and } m_m = \rho_m * \upsilon_m \quad (5)$$

Substitution of *Eq. (4)* back in to *Eq. (3)* it will give,

$$W_f = \frac{m_f}{m_c} = \frac{\rho_f * v_f}{\rho_c * v_c} = \frac{\rho_f}{\rho_c} * \frac{v_f}{v_c} = \frac{\rho_f}{\rho_c} V_f$$
$$W_m = \frac{m_m}{m_m} = \frac{\rho_m * v_m}{\rho_c * v_c} = \frac{\rho_m}{\rho_c} * \frac{v_m}{v_c} = \frac{\rho_m}{\rho_c} V_m \quad (6)$$

Again, the sum of weight of the fibers and the matrix will give us mass of the composite,

$$W_f + W_m = W_c \quad (7)$$

Adding W_f, W_m and W_c from *Eq. (3)* forward in to *Eq. (7)* give us,

$$\frac{1}{\rho_c} = \frac{W_f}{\rho_f} + \frac{W_m}{\rho_m} \quad (8)$$

For hybrid fiber reinforced composite, the above equations can be summarized to relate density, weight fraction of fibers and density of fibers as below. And all samples are prepared using this equation as a general formula.

$$\frac{1}{\rho_c} = \frac{W_{f1}}{\rho_{f1}} + \frac{W_{f2}}{\rho_{f2}} + \cdots \frac{W_{fn}}{\rho_{fn}} + \frac{W_m}{\rho_m} \quad (9)$$

Types of samples	Types of fibre/s	Fibre percentage by weight (%)	Mass of fibre (g)	Mass of resin (polyester) with allowance (g)	Mass of hardener (g)
GFRP	Glass	15	12.66	76.26	2
HFRP	Hair	15	11.88	72.97	2
SFRP	Sisal	15	12	73.73	2
HSFRP	Hair	7.5	5.97	72.34	2
	Sisal	7.5	5.97		
HGFRP	Hair	7.5	6.16	74.4	2
	Glass	7.5	6.16		
SGFRP	Sisal	7.5	5.24	74.4	2
	Glass	7.5	5.24		
HSGFRP	Hair	5	4	73.6	2
	Sisal	5	4		
	Glass	5	4		

Table 2. Mass percentage contribution of fibre and matrix
2. táblázat Ágyazóanyag és szál tömegszázalékos aránya

2.4 Sample preparation

This research used hand lay-up method for sample preparation due to its simplicity, flexibility, and cost-effectiveness, especially when dealing with low-volume production or custom-made parts. The **hand lay-up method** involves manually placing layers of reinforcement fibers (such as glass, carbon, or natural fibers) in a mold, followed by the application of a resin system. This method allows for precise control of fiber placement and orientation, which is critical in achieving the desired mechanical properties of the composite part. Due to its adaptability, this method can accommodate a variety of **fiber orientations**, such as **unidirectional, bidirectional, or random orientations**, making it suitable for both simple and complex geometries.

One of the major advantages of the hand lay-up method is its ability to produce **customized composite parts** without the need for expensive machinery or molds. It is ideal for **prototype production, small-batch manufacturing**, and applications that require **structural reinforcement in specific directions**.

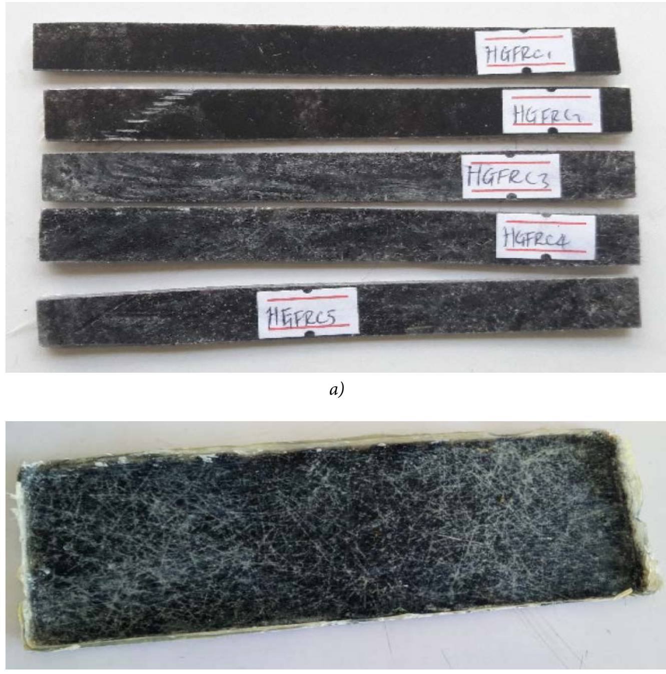

Fig. 2 a) Sample of Hair/glass fiber reinforced Plastics (HGFRP) for Flexural Test
b) Hair/glass fiber reinforced Plastics (HGFRP)
2. ábra a) Haj/üvegszál-erősítésű műanyag (HGFRP) minta hajlítószilárdság vizsgálathoz
b) Haj/üvegszál-erősítésű műanyag (HGFRP)

2.5 Experiments conducted

Tensile strength

Tensile test is done according to ASTM D638-03 with geometrical dimensions of 165 mm × 20 mm × 3 mm using UTM at the speed of 2mm/min [16, 17].

Flexural strength

The three-point bending test sample is prepared based on ASTM D790 and its dimension is 125 mm × 13 mm × 3 mm with the speed of using UTM [17].

Impact strength

The sample for impact test is made using ASTM D256 with a dimension of 64 mm × 13 mm × 3 mm. Charpy impact testing is done on five samples for each case to measure the energy absorption capacity of the given materials. Impact energy is the difference in potential energies of the striking pendulum at the beginning position before a strike and at the end position after the strike of the sample [18].

Water absorption test

Moisture absorption is done within distilled water using a very accurate techno test electronic balance and the sample is prepared according to ASTM D 570 which measures 30 mm × 28 mm × 3 mm [1].

3. Results and discussions

This section presents and analyzes the experimental results from the characterization of hair-sisal-glass fiber polyester hybrid composites. Key material properties, including tensile strength, flexural strength, impact resistance, and water absorption, are examined in detail. The effects of fiber composition, fiber-matrix bonding, and hybridization on the overall mechanical performance of the composite are evaluated based on the experimental data. All mechanical test results are systematically presented for clarity and comparison in *Table 3.*

a)

b)

c)

Fig. 3 a) Universal Testing Machine
b) Charpy impact Testing Machine
c) Electronic balance for Water Absorption Test
3. ábra a) Univerzális vizsgáló berendezés
b) Charpy kalapács
c) Elektromos mérleg vízfelvétel vizsgálathoz

Types of samples		Tensile strength (MPa)	Flexural load (N)	Flexural strength (MPa)	Impact energy (J)
GFRP	GFRP1	43.3	90	144.23	11
	GFRP2	41.28	50	80.13	11
	GFRP3	55.13	70	112.18	12
	GFRP4	40.51	90	144.23	9.5
	GFRP5	36.41	50	80.13	7.5
	Average	*43.33*	*70*	*112.18*	*10.2*
HFRP	HFRP1	16.28	20	112.18	10
	HFRP2	18.97	20	32.05	6
	HFRP3	17.69	20	32.05	7
	HFRP4	10.26	20	32.05	5
	HFRP5	18.21	20	48.08	9.5
	Average	*16.28*	*20*	*51.28*	*7.5*
SFRP	SFRP1	20	20	32.05	4.5
	SFRP2	16.15	50	80.13	7
	SFRP3	17.44	20	32.05	6.5
	SFRP4	16.41	40	64.1	5.5
	SFRP5	23.85	40	64.1	7
	Average	*18.77*	*34*	*54.49*	*6.1*
HSFRP	HSFRP1	22.8	40	64.1	6
	HSFRP2	18.72	20	32.05	8.5
	HSFRP3	30.26	20	32.05	11.5
	HSFRP4	19.74	20	32.05	4.5
	HSFRP5	22.56	40	64.1	8.5
	Average	*22.82*	*28*	*44.87*	*7.8*
HGFRP	HGFRP1	28.97	50	80.13	5
	HGFRP2	21.03	40	64.1	5
	HGFRP3	18.46	50	80.13	7.5
	HGFRP4	24.87	50	80.13	7.5
	HGFRP5	18.72	50	80.13	11.5
	Average	*22.41*	*48*	*76.92*	*7.3*
SGFRP	SGFRP1	19.87	70	112.18	4
	SGFRP2	24.87	90	144.23	5
	SGFRP3	15.64	70	112.18	5.5
	SGFRP4	16.15	50	80.13	5.5
	SGFRP5	22.82	50	80.13	8.5
	Average	*19.87*	*66*	*105.77*	*5.7*
HSGFRP	HSGFRP1	22.37	70	112.18	7.5
	HSGFRP2	29.74	50	80.13	10
	HSGFRP3	19.23	70	112.18	7.5
	HSGFRP4	23.08	70	112.18	7
	HSGFRP5	17.44	70	80.13	7.5
	Average	*22.37*	*66*	*99.36*	*7.9*

Table 3. Experimental Results of all Mechanical Properties test
3. táblázat Az összes mechanikai vizsgálat eredménye

The average values of the above results are summarized in *Table 4* below

Samples	Tensile strength (MPa)	Impact energy (J)	Flexural strength (MPa)	Water absorption (%)
GFRP	43.332	10.2	112.18	0.9447
HFRP	16.282	7.5	51.282	15.3979
SFRP	18.77	6.1	54.486	7.5829
HSFRP	22.82	7.8	44.87	8.7531
HGFRP	22.41	7.3	76.924	5.0827
SGFRP	19.87	5.7	105.77	2.8599
HSGFRP	22.894	7.9	105.77	3.4864

Table 4 Summary for average mechanical properties
4. táblázat Mechanikai vizsgálatok átlagainak összefoglalója

3.1 Tensile strength

Fig. 4 demonstrates that the tensile strength of sisal fiber reinforced plastics (SFRP) outperforms that of hair fiber reinforced plastics (HFRP). This difference is attributed to the high water-absorption nature of hair fiber and the comparatively better water uptake of sisal fiber. Despite hair fiber exhibiting exceptional tensile strength per strand, the presence of voids and discontinuities resulting from its high water-absorption leads to the reduced tensile strength of HFRP. Additionally, factors such as hair fiber length and orientation further contribute to the weakening of HFRP.

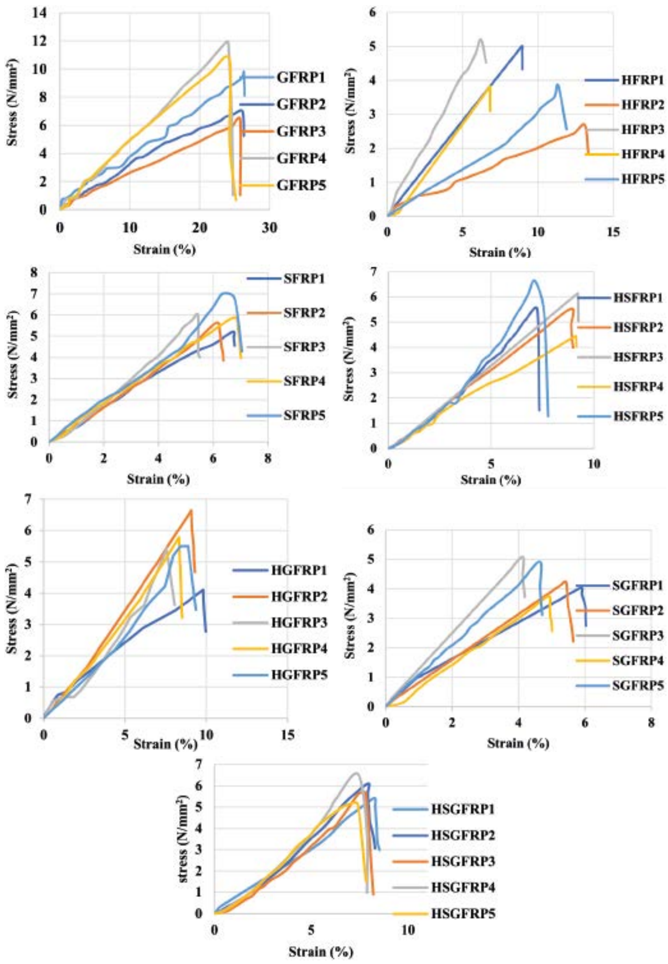

Fig. 4 Stress-Strain relation of the composites
4. ábra Kompozitok feszültség-fajlagos alakváltozás összefüggése

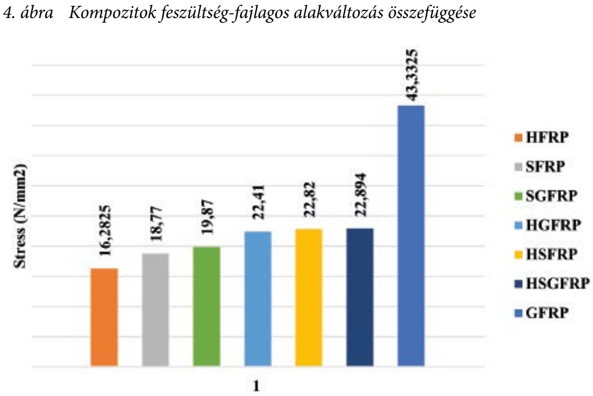

Fig. 5 Average Tensile Strength of the Materials
5. ábra Anyagok átlagos húzószilárdsága

The average values for tensile strength of each sample are summarized as in *Fig. 5* Hair/sisal/glass fiber reinforced plastics (HSGFRP) still exhibit the highest tensile strength compared to other fiber reinforced composite materials. However, it only satisfies 53% of the tensile strength of glass fiber reinforced plastics (GFRP). This aligns with the research objectives aimed at achieving intermediate strength for HSGFRP between GFRP and other natural and hybrid fiber reinforced composite materials.

3.2 Flexural strength

From *Fig. 6*, it is evident that the bending strength of sisal fiber reinforced plastics (SFRP) remains higher than that of hair fiber reinforced plastics (HFRP). This difference is attributed to the poor natural conduct of hair fiber compared to sisal fiber. The inherent shortcomings of hair fiber contribute to the formation of numerous discontinuities within the composite, leading to stress concentration and ultimately resulting in poor strength and premature failure under stress.

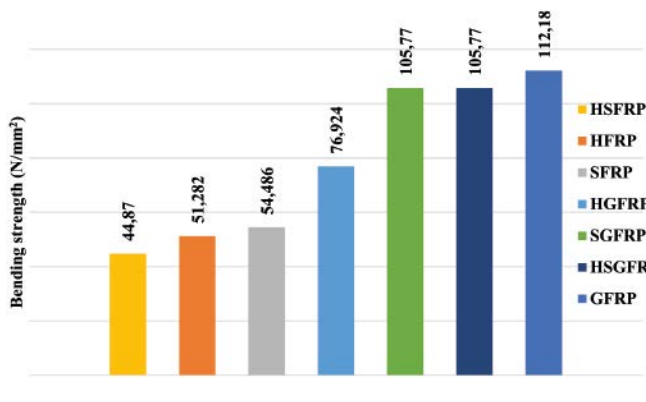

Fig. 6 Flexural strength of the composite
6. ábra Kompozit hajlító-húzószilárdsága

Interestingly, the combination of hair and sisal fiber reinforced plastics (HSFRP) exhibits significantly lower flexural strength compared to both sisal and hair fiber reinforced composites. This decrease in strength can be attributed to the cumulative negative effects of the two natural reinforcements. Moreover, HSGFRP satisfies 94% of the flexural strength of glass fiber reinforced plastics (GFRP). In summary, HSGFRP achieves a remarkable 94% of the flexural strength of GFRP.

3.3 Impact strength

Fig. 4 shows that, hair fiber reinforced plastics (HFRP) exhibits higher impact stress absorption compared to SFRP materials. This can be attributed to the good ductility nature of human hair, aligning with one of the objectives set at the beginning for including hair fiber as a reinforcement. Impact strength typically increases with the percentage weight of reinforcement until reaching an optimum limit, as depicted in the graph. The rise in impact strength is primarily attributed to the contribution of hair fiber.

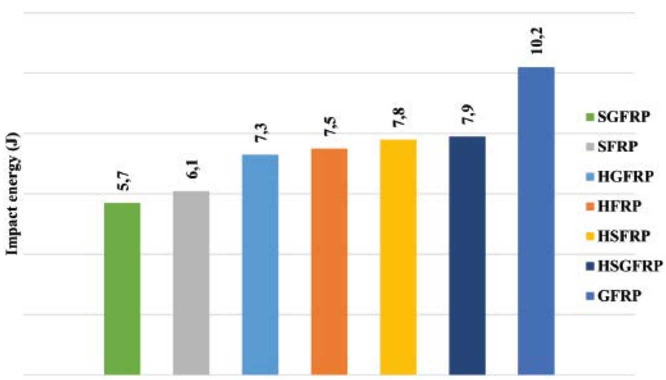

Fig. 4. Impact strength of the composites
4. ábra Kompozitok ütőmunkája

However, the addition of glass fiber has a negative effect on both HFRP and SFRP. This reversal is due to the absence of hair fiber, indicating that the inclusion of hair fiber up to its optimum point enhances impact strength. The impact strength of the required hybrid material (HSGFRP) remains satisfactory, primarily due to the presence of hair fiber.

In conclusion, hair/sisal/glass fiber reinforced polyester plastics (HSGFRP) fulfills approximately 77% of the impact strength of glass fiber reinforced polyester plastics (GFRP).

3.4 Water absorption

As depicted in *Fig. 5*, glass fiber reinforced composite has good water absorption, while hair fiber reinforced plastics (HFRP) shows the poorest behavior. Addition of glass fiber improves water absorption for both hair and sisal composites. Hair/sisal/glass fiber reinforced plastics (HSGFRP) exhibits a moderate absorption, 22% higher than sisal/glass composite, mainly due to hair fiber inclusion. Overall, HSGFRP displays favorable water absorption properties.

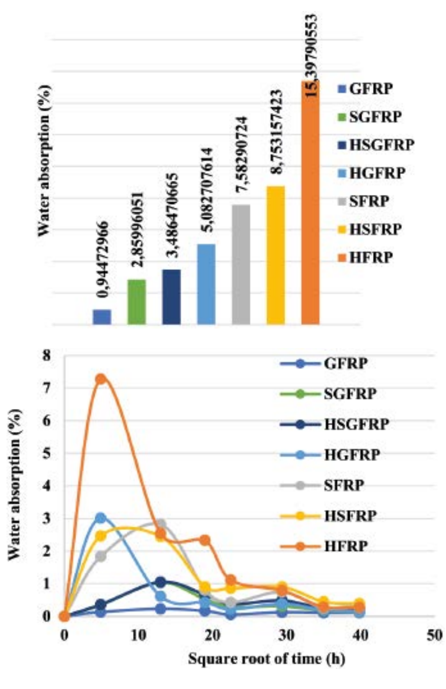

Fig. 5 Water Absorption Test Results of the Samples
5. ábra Minták vízfelvétel vizsgálatainak eredménye

4. Conclusions

The conclusions drawn from the study indicate that sisal fiber reinforced composite exhibits higher tensile and flexural strength but lower impact strength compared to hair fiber reinforced composite. The hair/sisal/glass fiber reinforced polyester plastics (HSGFRP) achieves 53% of the tensile, 94% of the flexural, and 77% of the impact strength of glass fiber reinforced Plastics (GFRP). The water absorption property of HSGFRP falls in the moderate range, following closely behind glass and glass/sisal fiber reinforced materials.

The addition of glass fiber enhances water absorption, tensile, and flexural strength but reduces impact strength in both hair and sisal fiber reinforced plastics. Overall, HSGFRP exhibits good mechanical properties compared to other hybrid fiber reinforced composites. However, there remains a notable gap, especially in tensile strength, between HSGFRP and GFRP.

Acknowledgments

I extend my heartfelt gratitude to God for guiding me throughout my journey. Special thanks to my advisor, Dr. Abraham D., for his invaluable support and guidance. My family, especially my older brother, deserves recognition for shaping my life. Thanks to all friends, colleagues, and departments for their contributions. Lastly, I'm grateful to Mizan-Tepi University for sponsorship.

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Építőanyag – Journal of Silicate Based and Composite Materials, Vol. 77, No. 1 (2025), 4–10 p.
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Öt szövetség együtt a hazai építőanyag-ipar jövőjéért – Megalakult a Szilikátipari Egyeztető Fórum

2025. június 12-én megalakult a Szilikátipari Egyeztető Fórum (SzEF), amely az építőanyag-gyártáshoz kapcsolódó szövetségek közötti szakmai együttműködést és közös fellépést hivatott erősíteni. Az alapító tagok: a Magyar Cement-, Beton- és Mészipari Szövetség (CeMBeton), a Magyar Kerámia Szövetség (MKSZ), a Magyar Építőanyag és Építési Termék Szövetség (MÉASZ), a Magyar Tégla és Tetőcserép Szövetség (MATÉSZ), valamint a Szilikátipari Tudományos Egyesület (SZTE).

A fórum célja, hogy a szövetségek közösen lépjenek fel az iparágat érintő legfontosabb szakpolitikai és gazdasági kérdésekben, összehangolják érdekképviseleti munkájukat, és közös állásfoglalásokkal, javaslatokkal segítsék az ágazat fenntartható fejlődését.

A CeMBeton tagsága a cement-, beton- és mésziparban működő vállalkozásokból, építéskémiai-, valamint laborcégekből áll, amelyek a modern építőipar szerkezeti alapját adják. A szövetség elkötelezett a körforgásos gazdaság, az alacsony karbonlábnyomú technológiák, az oktatási és a szabályozási környezet fejlesztése mellett.

A MATÉSZ a hazai tégla és tetőcserép gyártók szakmai érdekképviseleti szervezete. Fő feladata a hazai tégla- és cserépipari cégek összefogásával az ágazati érdekek érvényesítése Magyarországon és az Európai Unióban. A Szövetség a termelés gazdasági, jogi feltételeinek, a termékek minőségének javítása érdekében számos területen tevékenykedik.

A Magyar Építőanyag és Építési Termék Szövetség (MÉASZ) szakmai ernyőszövetségként fogja össze a hazai építőanyag-ipar öt szakszövetségét és számos további hazai gyártót. A MÉASZ tagjai a közvetlen működési környezetre vonatkozó érdekképviseleti munkán túl elkötelezettek mindazon ösztönzők és szabályozások kialakításában, amelyek innovatív és energiahatékony új építési beruházásokat, valamint minőségi épületkorszerűsítéseket, felújításokat eredményeznek. A Szövetség tagjai kulcsszerepet töltenek be a foglalkoztatás, a K+F és az oktatás terén az értékláncban.

A Magyar Kerámia Szövetség többek között a burkoló-, a szaniterkerámia-gyártó és a tűzállóanyag-ipari szereplők érdekeit is képviseli. E három szakterület nemcsak a lakó- és közösségi épületek komfortját határozza meg, hanem az építőanyag-ipar ipari hátterét is alakítja. A tűzálló kerámiák például elengedhetetlenek a cement- és üveggyártás magas hőmérsékletű technológiáihoz, így közvetve az építőanyag-gyártás értékláncának alapját is képezik.

A Szilikátipari Tudományos Egyesület (SZTE) a hazai anyagtudományi kutatások és mérnöki tudás központi platformja, amely összeköti az ipart, a tudományos életet és az oktatást. Szerepe kulcsfontosságú az utánpótlás képzésében és az innováció előmozdításában.

A SzEF működése négy fő pillérre épül: szakmai tudásmegosztás, összehangolt érdekképviselet, szakember-utánpótlás biztosítása és az iparági innováció – különösen a zöld technológiák – előmozdítása.

Az együttműködés célja, hogy az építőanyag-ipar teljes spektrumát képviselő szövetségek közös hangon szólaljanak meg a legfontosabb ágazati kérdésekben, hozzájárulva ezzel a hazai építésgazdaság stabilitásához, fenntarthatóságához és nemzetgazdasági súlyának növekedéséhez.

Budapest, 2025. június 13.