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Effect of Varying Filler Volume Fractions on Mechanical Properties of Sunflower Seed Husk-Reinforced Epoxy Composite

Manickavasaham G [1*], Balaguru P [2], Annamalai N [3]
[1] Research Scholar, Department of Mechanical Engineering, Annamalai University, Chidambaram, 608002, Tamil Nadu, India.
[2] Professor, Department of Mechanical Engineering, Annamalai University, Chidambaram, 608002, Tamil Nadu, India.
[3] Professor, Department of Mechanical Engineering, Mookambigai College of Engineering, Pudukkottai, 622502, Tamil Nadu, India.

Abstract
The present study explores the mechanical properties of a polymer composite material composed of an epoxy matrix and sunflower seed husk (SSH) filler. The objective is to investigate the effect of varying filler volume fractions, ranging from 0 to 50 per cent, on the mechanical properties of the composites, namely, tensile, flexural, compression, hardness and impact strength tests. Additionally, scanning electron microscopy images (SEM) were used to analyze the fracture characteristics of the tensile and flexural test specimens. The findings of this research will provide valuable insights into the potential applications of the epoxy-sunflower seed husk composite, shedding light on its mechanical properties. Results demonstrate a reduction in mechanical properties with the addition of SSH filler to the epoxy-based composite, except the impact strength due to higher amount of debonding in the composites.
Key words: Epoxy, Sunflower seed husk, Mechanical properties.

1. Introduction

Natural filler polymer matrix composites (PMC) have gained considerable interest as a sustainable alternative to conventional composites in light loading applications. By incorporating natural fillers, such as plant fibers or husks, into polymer matrices, these composites offer generally improved mechanical properties, reduced environmental impact, and potential cost savings. The utilization of nanoclay greatly enhances the adherence and compatibility between hemp fiber and the polypropylene matrix, leading to improved composite performance [1] this increases the strength of composites. The addition of high concentrations (25%) of $CaCO_3$ to the High Density Polyethylene polymer matrix, without the need for talc, substantially enhances its mechanical properties [2]. As the dolomite dust content increases, there is a progressive decline in both the tensile and flexural strength of the material [3]. By incorporating 35% glass fiber/carbon fiber and 0.6 wt% Cobalt content into the epoxy resin, significant improvements in both tensile and flexural strength can be achieved [4]. The mechanical properties of the composites exhibit an incremental improvement as the percentage of tectona grandis wood dust increases [5]. Egg shell powder demonstrates promising potential as an alternative to talcum powder and $CaCO_3$, offering new possibilities for filler materials [6]. The synergistic combination of tamarind seed powder and palm fiber powder presents a viable approach for fabricating composite structures with desirable mechanical properties [7]. Enhanced bonding between Polyalthia Longifolia Seed Filler –Vinyl Ester is observed when the filler loading reaches 25 wt%, resulting in optimized flexural strength and minimal void formation [8]. By incorporating an optimal amount of jute fiber along with glass fiber, the mechanical properties of the composites can be significantly improved [9]. The inclusion of peanut oil cake extracted cellulose micro filler powder effectively reduces porosity, fiber breakages, and matrix breakages within the composite [10]. The incorporation of bio-fillers offers a promising solution for the development of natural fiber composites or bio-composite materials, making them highly suitable for the competitive composites market after appropriate optimization [11]. The utilization of higher filler content (12 wt %) in honeycomb structures leads to a trade-off, resulting in reduced impact resistance and hardness properties [12]. Increasing the filler loading yields a more pronounced enhancement in impact strength, contributing to the overall mechanical performance of the composite [13]. The presence of voids and significant gaps at 20% wt Tamarind Seed Filler (TSF) content indicates inadequate bonding between TSF and Vinyl Ester, thereby impacting the strength of the composite [14]. The mechanical properties of the composites exhibit a rapid decline when the content of Walnut Shell powders exceeds 0.5 wt% [15]. Bio-composites formulated with untreated Pecan Nutshell (PNS) demonstrate noticeable gaps between the filler and the matrix; however, this effect is mitigated in bio-composites with treated PNS, where improved interactions between the matrix and filler are observed [16]. Incorporating 20 percentage and 30 percentage red mud into sisal/polyester hybrid composites leads to agglomeration and an increase in void formation, affecting the overall composite quality [17]. Voids act as stress concentrators, and minimizing their presence would have significantly improved the strength results of the composite [18]. The incorporation of fishbone nano powder in polymer composites yields remarkable improvements in both flexural modulus and strength, enhancing the overall performance of the material [19]. The impact strength of the composite is influenced by critical factors such as fiber pull-out and the degree of adhesion, contributing to its superior impact resistance [20]. The strength and stiffness of Polypropylene composites reinforced with natural fillers are strongly influenced by the content and size of the fillers, shaping the mechanical behavior of the composite material [21]. The mechanical properties are notably affected by the particle size of waste groundnut shells and coir fibers, emphasizing the significance of particle dimensions in composite performance [22]. This study investigates the use of natural fillers, specifically sunflower seed husk, in Polymer Matrix Composite (PMC) to assess its influence on mechanical properties, namely, tensile, compression, flexural, hardness and impact strength.

2. Materials and Methods

2.1 Materials

The process of obtaining sunflower seed husk particles involved several steps. Initially, the husks were collected from a local farm. To ensure cleanliness, the husks were cleaned by rinsing them with water to remove any impurities. Afterward, they were dried under direct sunlight for duration of eight hours. Once the husks were dry, they were crushed until they reached a particle-like consistency. The resulting particles were then subjected to sieving to obtain a desired particle size distribution, as depicted in Table 1. For the preparation of the composite, epoxy resin (LY556) and hardener (HY951) were used. The mixing ratio employed was 10 parts epoxy resin to 1 part hardener as described elsewhere [5, 10, 20, 22].

Table 1. Particle Size Distribution Characteristics of Sunflower Seed Husk Filler

Material	Volume Median Diameter		
	Dv (10) µm	Dv (50) µm	Dv (90) µm
Sunflower Seed Husk Filler	79.8	244.0	463.0

2.2 Preparation of composite and Testing of fabricated specimens

The epoxy resin was accurately measured on a precise weighing scale before being poured into the beaker, ensuring compliance with the specified sample composition. Following that, the SSH filler was added to the epoxy resin in accordance with the prescribed composition ratio, and the two components were thoroughly mixed until fully blended. Subsequently, the hardener was carefully measured and introduced into the epoxy-filler mixture, after which the entire mixture was stirred for duration of ten minutes, maintaining a 10:1 ratio of epoxy to hardener. The resulting mixture was then poured into a mild steel mould with dimensions measuring 210 x 170 x 3 mm. To facilitate easy removal of the specimen from the mould, a layer of wax was applied to its surface. Subsequently, a consistent load of 9806.65 N was applied to the mould for a continuous period of 24 hours within the compression moulding setup. Once the curing process was completed, test specimens were fabricated in accordance with the relevant ASTM standards for Tensile test (ASTM D638), Flexural test (ASTM D790), Compression test (ASTM D3410), Impact test (ASTM D256) and Hardness (ASTM D2240). All tests were conducted with three replications, and the average values are presented in the test results.

2.3 Scanning Electron Microscopy Analysis

To analyze the failure surface of composite samples, a scanning electron microscope (SEM) was employed. The fractured sections of the tensile and flexural specimens were carefully prepared and imaged using an acceleration voltage of 10 kV. The resulting SEM images were taken at a magnification of 500x, allowing for a clear visualization of the fractures that occurred during the tensile and flexural tests.

Table 2: Mechanical Properties of Neat Epoxy and Particulate Filled Epoxy Composites

Sample ID	Tensile strength (MPa)	Flexural Strength (MPa)	Compression strength (MPa)	Hardness (Shore D)	Charpy Impact (J/cm^2)	Toughness (KJ/m^3)
SSH-0	32.967 ±1.402	57.233 ±4.535	40.667 ±1.923	84.333 ±0.308	3.669 ±0.037	335.2186 ±19.533
SSH-5	25.567 ±0.437	47.500 ±2.2	40.667 ±1.923	84.333 ±0.436	3.920 ±0.024	173.6101 ±6.795
SSH-10	23.767 ±0.141	42.767 ±1.432	38.667 ±1.411	84.333 ±0.533	4.090 ±0.061	179.9407 ±26.526
SSH-15	21.633 ±0.693	38.367 ±1.022	37.667 ±0.533	83.222 ±0.272	4.427 ±0.208	164.2286 ±7.367
SSH-20	20.200 ±0.562	35.000 ±0.423	37.333 ±0.533	83.111 ±0.37	5.120 ±0.154	142.3725 ±11.636
SSH-25	19.533 ±0.107	34.033 ±0.324	35.667 ±0.533	83.000 ±0.308	5.643 ±0.088	132.1569 ±1.447
SSH-30	18.967 ±0.417	32.767 ±0.324	34.667 ±1.411	82.778 ±0.272	6.207 ±0.093	115.6837 ±8.189
SSH-35	18.667 ±0.267	30.700 ±0.37	33.333 ±0.533	82.333 ±0.436	6.530 ±0.162	108.3415 ±8.624
SSH-40	17.767 ±0.282	29.167 ±0.525	32.333 ±0.533	80.444 ±0.325	6.660 ±0.009	101.3834 ±16.385
SSH-45	16.367 ±0.427	26.767 ±0.437	30.667 ±0.533	79.667 ±0.308	6.817 ±0.011	107.7300 ±6.407
SSH-50	15.133 ±0.35	23.767 ±2.214	29.333 ±1.067	78.667 ±0.436	6.849 ±0.028	81.6109 ±10.758

3. Results and Discussion

3.1 Tensile Strength

The experimental results revealed a clear inverse relationship between filler content and tensile strength. As the filler content increases, the tensile strength of the composites consistently decreases similar to the findings of Sánchez-Acosta et al [16], Erdogan [21] and Agunsoye [24]. Sample SSH-5, containing 5 percent filler material, exhibited a tensile strength of 25.567 ± 0.437 MPa, while sample SSH-50, with 50 per cent filler content, displayed (Table 2) the lowest tensile strength of 15.133 ± 0.35 MPa. The observed decrease in tensile strength with increasing filler content can be attributed to several underlying mechanisms. Firstly, the introduction of filler material disrupts the continuity of the composite structure. This disruption leads to stress concentrations and weakens the material, resulting in a reduced tensile strength. As the filler content increases, the number of stress concentration sites also increases, further contributing to the weakening of the composite. Additionally, the bonding between the filler material and the matrix may not be as strong as the bonding between matrix phases. This weaker bonding between the filler and matrix interfaces can act as preferential failure points, diminishing the overall tensile strength of the composite. Furthermore, at higher filler percentages, the increased presence of filler particles hinders efficient load transfer between the matrix phases, thereby reducing the tensile strength. There is a significant drop (about 22.4%) in tensile strength between SSH-0 and SSH-5, indicating that even a small addition of filler content has a noticeable impact. As a typical example depicted in Figure 1(a) for Sample ID SSH-25, we observe the material's response under tensile loading. The stress-strain curve highlights its ability to withstand stretching forces, revealing key insights into its structural integrity and deformation characteristics.

From Table 3, the negative slope values indicate that as the filler content increases, the tensile strength tends to decrease. This suggests that the presence of fillers in the material has a weakening effect on its tensile strength. The magnitude of the slope values can provide insights into the extent of the tensile strength reduction with increasing filler content. Larger slope values, such as -1.48 and -0.4268, indicate a more significant decrease in tensile strength per 5% increase in filler content. Larger negative slopes indicate that pores expand within the composite, contributing to an increased overall porosity of the composite and creating high stress concentrations that weaken the material. This leads to lower stiffness, localized strain concentrations, changes in fracture mechanisms, and reduced ductility. Smaller slope value -0.0600 suggest that a more gradual decline in tensile strength as filler content increases and it indicating a moderate weakening effect.

Table 3: Relationship between Slope and Mechanical Properties of a Material

Slope	Volume Fraction (%)	Slope for Tensile strength	Slope for Compression strength	Slope for Flexural strength	Slope for Hardness	Slope for Impact strength
m_1	0-5	-1.4800	0	-1.9466	0	0.0502
m_2	5-10	-0.3600	-0.4000	-0.9466	0	0.0340
m_3	10-15	-0.4268	-0.2000	-0.8800	-0.2222	0.0674
m_4	15-20	-0.2866	-0.0668	-0.6734	-0.0222	0.1386
m_5	20-25	-0.1334	-0.3332	-0.1934	-0.0222	0.1046
m_6	25-30	-0.1132	-0.2000	-0.2532	-0.0444	0.1128
m_7	30-35	-0.0600	-0.2668	-0.4134	-0.0890	0.0646
m_8	35-40	-0.1800	-0.2000	-0.3066	-0.3778	0.0260
m_9	40-45	-0.2800	-0.3332	-0.4800	-0.1554	0.0314
m_{10}	45-50	-0.2468	-0.2668	-0.600	-0.2000	0.0064

3.2 Flexural Strength

The highest flexural strength value of 57.233 MPa was obtained for the composite sample with no filler (SSH-0). As the sunflower seed husk filler content increases, the flexural strength progressively decreases, reaching the lowest value of 23.767 MPa for the sample with 50% filler content (SSH-50) as shown in Table 2. A trend of decreasing flexural strength is observed as the filler content (Vf %) increases, similar to the findings of Sánchez-Acosta et al [16] and Erdogan [21]. The decrease in flexural strength can be attributed to several factors. One possible reason is the difference in stiffness between the sunflower seed husk filler and the epoxy resin matrix. The addition of a relatively less stiff filler material can lead to a reduction in the overall stiffness of the composite, resulting in decreased resistance to bending forces. Inadequate bonding or weak interfacial adhesion between the sunflower seed husk filler and the epoxy resin matrix can further contribute to the decrease in flexural strength. SSH-5 experiences a significant decrease of approximately 17.0% compared to

SSH-0. This drop in Flexural Strength amounts to approximately 9.733 MPa. As a typical example illustrated in Figure 1(b) for Sample ID SSH-25, provides valuable data on the composite's performance under bending loads. The stress-strain curve sheds light on its resistance to bending stresses, aiding in understanding its flexural behavior and potential applications.

In Table 3, negative slopes indicate a decreasing trend in flexural strength as the filler content increases. This suggests that higher filler content weakens the material's flexural strength. The magnitude of the slope values reflects the rate of decrease in flexural strength per 5% increase in filler content. Larger slope values, such as -1.9466 and -0.9466, indicate a more significant decrease in flexural strength compared to smaller slope values like -0.1934 and -0.2532. A higher negative slope in the context of flexural strength can indeed indicate that the material is experiencing different modes of failure. These failure modes could include interfacial debonding, matrix cracking, or other forms of failure associated with the presence of voids. The steeper decline in strength suggests that the material becomes more vulnerable to these failure mechanisms as the applied load or stress increases. Conversely, lower negative slope values imply that the material's flexural strength may exhibit a more gradual reduction, suggesting a comparatively milder susceptibility to failure mechanisms as the load or stress increases.

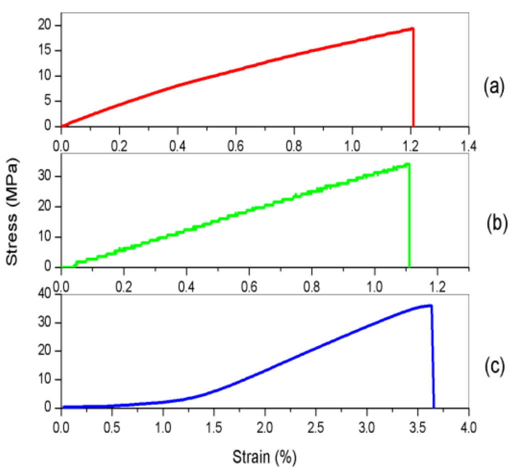

Figure 1. Stress-Strain Curves for Sample ID SSH-25: (a) Tensile Strength, (b) Flexural Strength, (c) Compression Strength

3.3 Compression Strength

The results obtained from the experiment (Table 2) indicate that the compression strength of the epoxy resin matrix decreases as the filler content of sunflower seed husk increases. This trend is in good agreement with Lakshumu Naidu and Kona [20]. The compression strength of the matrix without any filler (SSH-0) was measured at 40.667 MPa. As the filler content increased from 5% (SSH-5) to 50% (SSH-50), the compression strength gradually decreased. The highest compression strength among the samples was observed at 5% filler content (SSH-5) with a value of 40.667 MPa. At higher filler contents (30 percent to 50 percent), a more significant reduction in compression strength was observed. The lowest compression strength was recorded at 50 percent filler content (SSH-50) with a value of 29.333 MPa. The decrease in compression strength with increasing filler content can be attributed to the inclusion of sunflower seed husk, which introduces porosity and reduces the overall density of the composite material. The presence of pores and voids within the matrix reduces the load-bearing capacity and leads to a decrease in compression strength. Figure 1(c) showcases the Compression Strength analysis for Sample ID SSH-25, as a typical example enabling us to delve into its capacity to withstand compressive forces. The stress-strain curve under compression reveals important aspects of the material's structural stability and load-bearing capabilities.

The slope values provided in Table 3 offer insights into the relationship between filler content and compression strength, illustrating how changes in filler content influence the material's compression strength. A slope of 0 indicates no significant change in compression strength within the 0-5% filler content range. The magnitude of the slope values reveals the extent of compression strength decrease per 5% increase in filler content. Larger slope values, such as -0.4 and -0.3332, indicate a more pronounced decrease in compression strength compared to smaller slope values like -0.0668. Larger negative slopes demonstrate the material's sensitivity to changes in the specified variable and the potential occurrence of failure mechanisms, such as localized buckling or crushing due to expanded pores. In contrast to higher negative slopes, smaller negative slopes suggest a milder decline in localized buckling or crushing due to expanded pores.

Compression-to-Tensile Strength Ratio (C/T) provided in the Table 4, it is observed that the C/T ratios generally increase as the filler content increases. This indicates a shift in mechanical behavior toward compression dominance. At a filler content of 0%, the C/T ratio is 1.2336. This indicates that the material is slightly more favorable for compressive loading but still has relatively balanced behavior between compression and tension. For filler content of 50%, the C/T ratio is 1.9383. This higher C/T ratio suggests that the material is increasingly better suited for applications involving compressive loading. It implies that the material's structural integrity and load-bearing capabilities are more pronounced in compression compared to tension.

Looking at the specific Compression-to-Tension Yield Stress Ratio (C:T) in the Table 4, sample SSH-25 (C:T Ratio: 0.15781) and sample SSH-50 (C:T Ratio: 0.12004) have lower C:T ratios, indicating that these materials are relatively stronger in tension compared to compression. They exhibit higher strength in resisting tensile forces before undergoing plastic deformation. Sample SSH-5 (C:T Ratio: 0.48614) demonstrates a relatively higher C:T ratio, indicating that the material is relatively stronger in compression compared to tension. It suggests that the material is better suited for applications where compressive forces dominate.

3.4 Hardness

The hardness values show a decreasing trend as the filler content increases, a similar trend was followed by Vigneshwaran et al [17]. For samples containing filler content ranging from 0% to 10%, the hardness remains relatively constant at approximately 84.333 ± 0.533 Shore D. However, as the filler content exceeds 10%, the hardness experiences a more noticeable decline. The higher filler content results in a decreased proportion of the polymer matrix within the composite. Given that the polymer matrix typically possesses greater hardness compared to most fillers, a decrease in the polymer-to-filler ratio contributes to an overall reduction in hardness. Moreover, higher filler content can induce alterations in the material's microstructure, leading to a distinct morphology that impacts hardness. The most significant drop in hardness occurs between samples SSH-15 (15% filler content) and SSH-20 (20% filler content), where the hardness decreases from 83.222 ± 0.272 Shore D to 83.111 ± 0.37 Shore D. This trend persists as the filler content continues to increase, with a gradual decline in hardness evident in Table 2. Notably, the sample with the highest filler content, SSH-50 (50% filler content), demonstrates the lowest hardness of 78.667 ± 0.436 Shore D.

The data provided in Table 3 reveal that Shore D hardness decreases with increasing filler content. The negative slopes indicate diminishing hardness with higher filler content. Worth noting is that at lower levels of filler content (0-5% and 5-10%), the slope values are close to zero, indicating a point of saturation or an optimal range where the addition of more filler does not significantly affect the hardness. This suggests the existence of an optimum filler content that balances the desired hardness with other material properties. Larger negative slopes, such as -0.3778 and -0.2, indicate a more pronounced decrease in hardness for each 5% increase in filler content. Conversely, smaller slopes like -0.0222 and -0.1554 represent a relatively minor reduction in hardness per 5% increase in filler content. Aggregation or clustering of fillers within the composite can create regions with lower hardness, resulting in a higher slope value. Additionally, the polymer matrix might exhibit resilience or stability against hardness reduction, leading to smaller slope values within the tested filler content range.

3.5 Impact Energy

The Charpy impact strength (Table 2) displays an increasing trend as the filler content increases. Samples with lower filler contents, such as SSH-0 and SSH-5, exhibit relatively lower Charpy impact strengths ranging from 3.669 to 3.920 J/cm^2. The most significant increase in impact strength is observed between samples SSH-15 (15% filler content) and SSH-20 (20% filler content), where the Charpy impact strength elevates from 4.427 to 5.120 J/cm^2. This trend persists as the filler content continues to increase, showing a gradual and consistent rise in impact strength. This finding is consistent with the observations made by Stalin et al. [8,14]. Remarkably, the sample with the highest filler content, SSH-50 (50% filler content), exhibits the highest Charpy impact strength of 6.849 J/cm^2. Reinforcing filler facilitate effective load transfer between adjacent regions, distributing applied forces more evenly, particularly during impact events.

The positive slopes from Table 3 indicate an increasing trend in impact strength as the filler content increases. This suggests that higher levels of filler content result in higher impact strength values. The magnitude of the slope values reflects the rate of change in impact strength with respect to the increase in filler content. Larger positive slopes, such as 0.1386 and 0.1128, indicate a more significant increase in impact strength for each 5% increase in filler content. Conversely, smaller slopes like 0.0064 and 0.026 represent a relatively smaller improvement in impact strength per 5% increase in filler content. These findings suggest that the addition of filler material has a positive influence on the impact strength of the composite material. The increase in impact strength can be attributed to various factors, such as improved energy dissipation, enhanced toughness, or a more efficient load transfer mechanism. It is interesting to note that the slope values vary across different ranges of filler content. In the lower range (0-20%), the slope values are relatively larger, indicating a more pronounced increase in impact strength with increasing filler content. However, as the filler content reaches higher levels (above 20%), the slope values become smaller, indicating a diminishing effect on impact strength improvement.

Table 4. Comparison of Compression and Tensile Strength Ratios and Yield Stress Ratios for Variable Filler Content

Sample ID	Filler Content (V_f %)	Compression-to-Tensile Strength Ratio (C/T)	Compression-to-Tension Yield Stress Ratio (C:T)
SSH-0	0	1.2336	0.24874
SSH-5	5	1.5906	0.48614
SSH-10	10	1.6269	0.22724
SSH-15	15	1.7412	0.17673
SSH-20	20	1.8482	0.31905
SSH-25	25	1.8260	0.15781
SSH-30	30	1.8278	0.25021
SSH-35	35	1.7857	0.22283
SSH-40	40	1.8198	0.26516
SSH-45	45	1.8737	0.21025
SSH-50	50	1.9383	0.12004

3.6 Toughness

From the data presented in the Table 2, it can be observed that as the filler content increases, the toughness of the material generally decreases. This trend suggests that the addition of filler material has a negative impact on the material's ability to absorb energy and deform without fracturing. The decrease in toughness with increasing filler content can be attributed to factors such as reduced intermolecular bonding, increased stiffness, or changes in the microstructure of the material. For instance, in the SSH-0 sample with no filler content, the high toughness value of 335.2186 KJ/m^3 indicates its superior ability to withstand impact and deformation. However, as the filler content increases, the toughness progressively decreases. This is evident in samples SSH-5 to SSH-50, where the toughness values range from 173.6101 to 81.6109 KJ/m^3.

3.7 Scanning Electron Microscopy Analysis

Figures (2)-(3) illustrate the scanning electron microscope (SEM) micrographs displaying the surfaces of fractured specimens of SSH filler-epoxy composites. These specimens were subjected to both tensile and flexural tests. The figure 2(a) contains 5% filler; 2(b) contains 10% filler, and so on until 2(j) which contains 50% filler. The same pattern applies to Figure 3. The SEM images clearly indicate that inadequate bonding between the SSH filler and epoxy is evident due to the presence of voids, cracks, and a noticeable gap within the specimen's surface. As the filler loading increases, the amount of matrix within the composite system decreases, leading to issues such as de-bonding, voids, weak interfacial bonding, and filler pullout. Consequently, the low affinity between the matrix and reinforcement results in reduced tensile strength and flexural strength. The majority of the SEM images prominently depict roughness and irregularities, specifically "crazes" and "serrations," on the fractured surface. This surface morphology resembles that typically observed in the brittle fracture of materials, commonly referred to as a "facet." Even though the material is brittle in nature, it is considered to be ductile because in polymer composites more than 2% ductility cannot be expected. These observations suggest that the material exhibits reduced resistance to crack propagation, resulting in brittle fracture behavior, which is in agreement with the findings of Hamed Salehian et al [23]. As the percentage of filler material increases, there is a large volume of mismatch between the polymer and filler material. When the chain is broken more serrations are formed as shown in SEM images.

4 Conclusions

The composite materials made by incorporating sunflower seed husk filler into epoxy resin were successfully fabricated and investigated. Increasing filler content in the material leads to a decrease in mechanical properties.

The following factors contribute to the reduction in mechanical properties:

- The introduction of filler material disrupts the continuity of the composite structure, leading to stress concentrations.
- At higher filler percentages, the increased presence of filler particles hinders efficient load transfer between the matrix phases. This hampers the material's ability to withstand tensile forces and reduces its tensile strength.
- The increase in filler content can lead to reduced intermolecular bonding within the material. This reduction in bonding strength can contribute to a decrease in toughness.
- The difference in stiffness between the filler and the epoxy resin matrix, as well as inadequate bonding or weak interfacial adhesion, contributes to the decrease in flexural strength. This suggests that the presence of filler weakens the overall structural integrity and load-bearing capacity of the material.

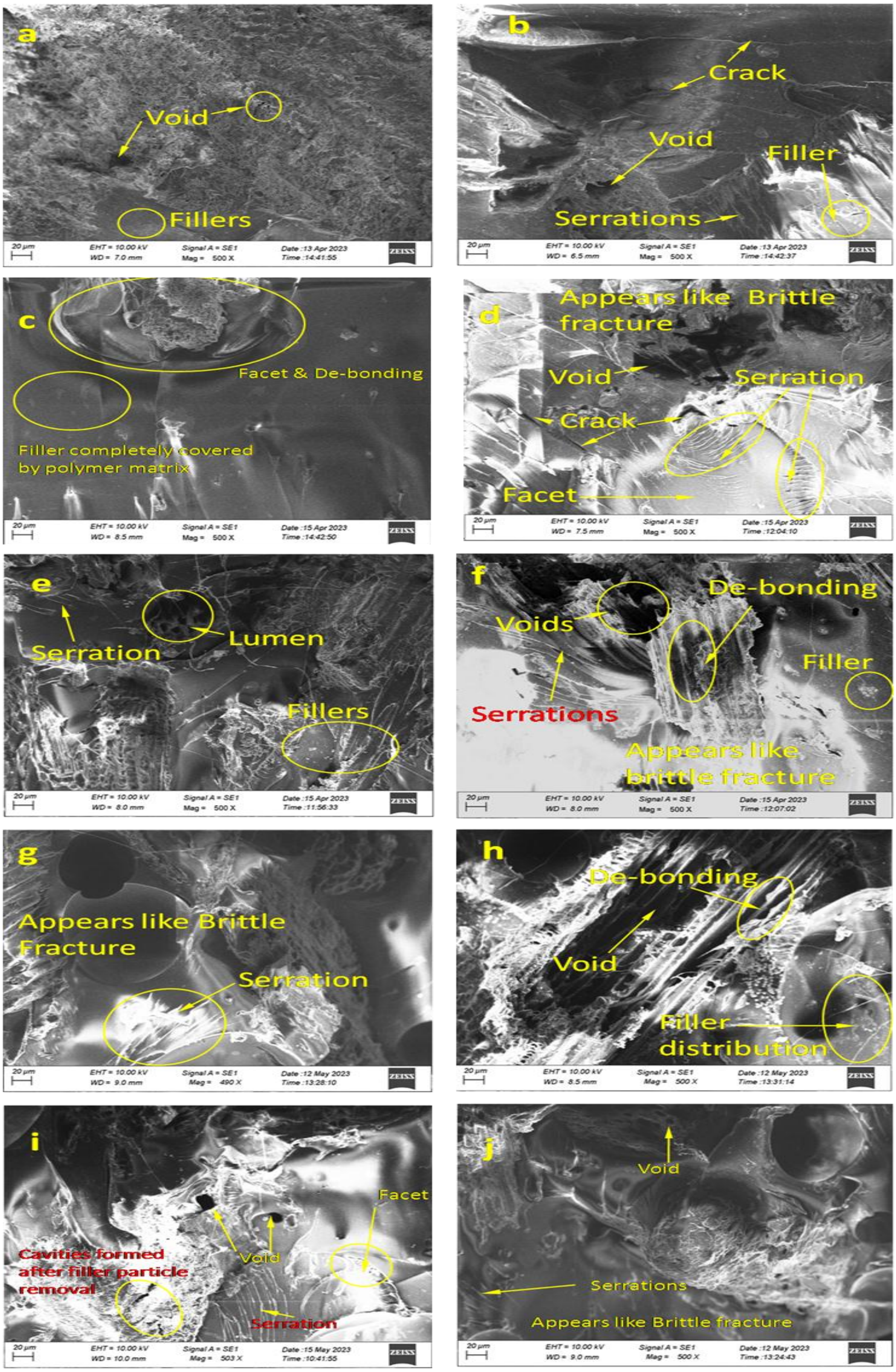

Figure 2: SEM Images of fractured tensile strength specimens of SSH filler-epoxy composites with varying filler content of 5 to 50 V_f%.

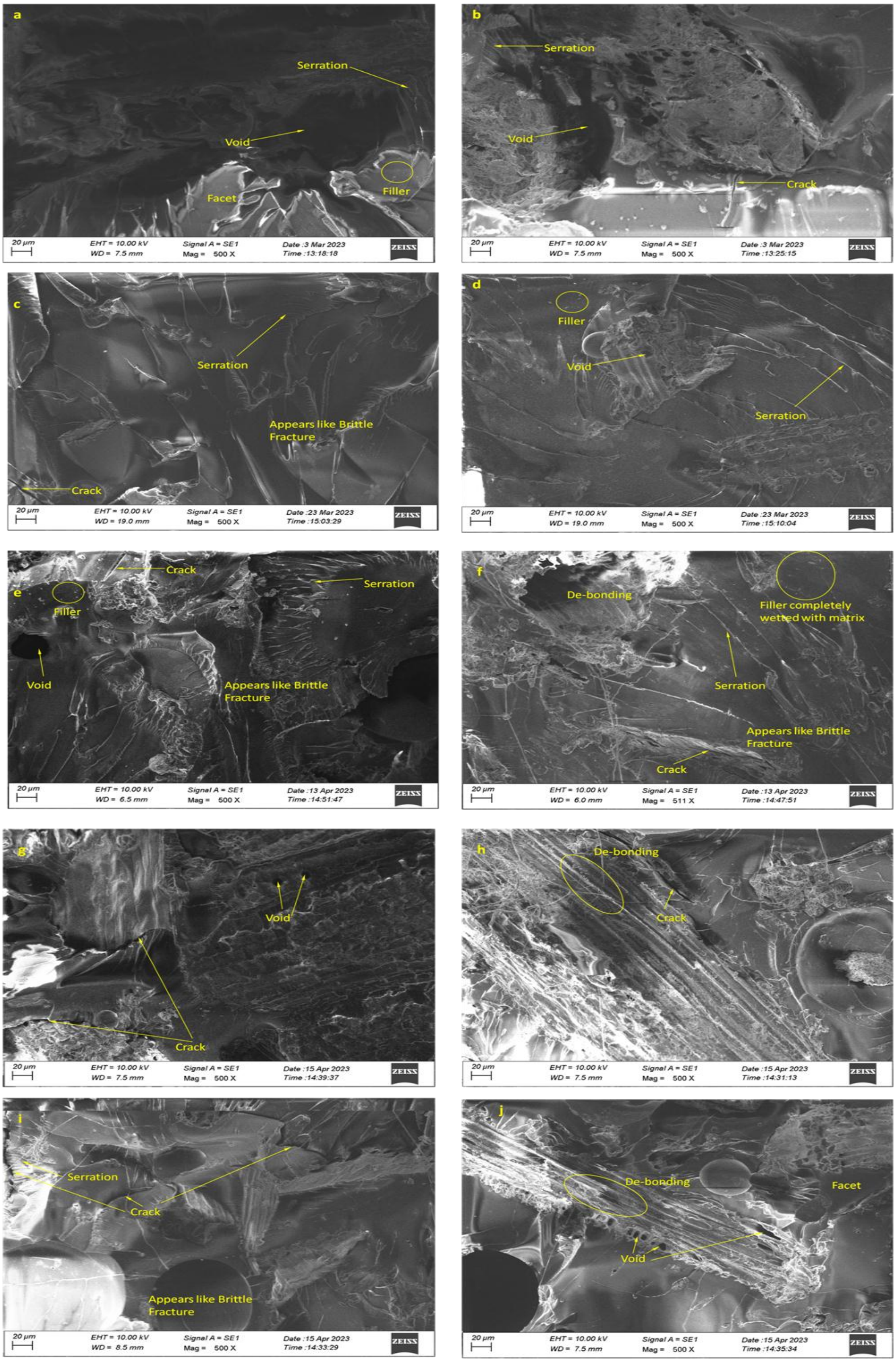

Figure 3: SEM Images of fractured flexural strength specimens of SSH filler-epoxy composites with varying filler content of 5 to 50 V_f%.

Interestingly, the Charpy impact strength improves as the filler content increases. This implies that the addition of filler enhances the material's ability to withstand sudden impact or shock loading. The morphological analysis of SSH filler-epoxy composites indicates inadequate bonding and a tendency for brittle fracture behavior, emphasizing the need for improved interfacial bonding and enhanced mechanical properties in composite materials.

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