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Analysis of the Impact Toughness of Boehmeria Nivea Fiber-Reinforced Composites with UHMWPE Matrix as Potential Biomaterials

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Abstract

Bone implants are generally made of metal materials that have the strength and toughness to fuse broken or fractured bones, but they have the disadvantage of causing pain due to the metal's ability to absorb ambient temperatures and the relatively high cost of implant materials. Therefore, Ultra High Molecular Weight Polyethylene (UHMWPE) reinforced with hemp fiber is needed. This study aims to analyze impact toughness and observations on fracture cross-sections. This study uses a composite of hemp fiber (SR) with a UHMWPE (UP) matrix, which will be made using the hot press method. The research method used is an experimental method to determine the effect of adding material mixtures by varying the volume fraction of the composite fiber. The volume fraction variations used included 3% SR: 97% UP, 5% SR: 95% UP, and 7% SR: 93% UP. The test specimens referred to the ASTM D5942 standard for impact testing. The impact test results showed that the highest impact toughness value was 0.0514 J/mm2 in the 3%SR : 97%UP variation and the lowest impact toughness value was 0.0478 J/mm2 in the 7%SR : 93%UP variation. SEM observations of the fracture cross-section revealed failures caused by fiber pull-out, debonding, and matrix cracking

Keywords: *bone implant plate; composite; impact test; Scanning Electron Microscopy; tensile test.*

Abstrak

Bone implant umumnya terbuat dari material logam yang memiliki kekuatan dan ketangguhan dalam menyatukan tulang patah atau retak, tetapi memiliki kelemahan dapat menimbulkan rasa nyeri dikarenakan sifat logam yang mampu menyerap suhu lingkungan dan material implant yang relatif mahal. Oleh karena itu, diperlukan material Ultra High Molecular Weight Polyethilene (UHMWPE) berpenguat serat rami. Penelitian ini bertujuan untuk menganalisis ketangguhan impak dan pengamatan pada penampang patahan. Pada penelitian ini menggunakan komposit dari serat rami (SR) dengan matriks UHMWPE (UP) yang akan dibuat dengan metode hot press. Metode penelitian yang digunakan yaitu metode eksperimental untuk mencari pengaruh penambahan campuran bahan dengan memvariasikan fraksi volume serat komposit. Variasi fraksi volume yang digunakan meliputi 3%SR : 97%UP, 5%SR : 95%UP, dan 7%SR : 93%UP. Spesimen pengujian mengacu pada standar ASTM D5942 untuk pengujian impak. Hasil pengujian impak diperoleh bahwa nilai tertinggi ketangguhan impak sebesar 0,0514 J/mm2 pada variasi 3%SR : 97%UP dan nilai terendah ketangguhan impak sebesar 0,0478 J/mm2 pada variasi 7%SR : 93%UP. Hasil pengamatan SEM penampang patahan terdapat kegagalan yang disebabkan oleh fiber pull out, debonding dan matriks crack.

Kata kunci: bone implant plate; komposit; Scanning Elektron Microscopy ; uji impak; uji tarik

1. Introduction

Fibers are small filaments made from natural or synthetic materials, with a minimum aspect ratio of 100 times and flexible and strong characteristics. Fibers are grouped into three categories: natural fibers, semi-synthetic fibers, and synthetic fibers. Natural fibers serve as reinforcing agents for certain polymer matrices and have been widely used in biomedical applications such as drug delivery, tissue engineering, and orthopedics. [1].

Natural fibers have considerable potential as an environmentally friendly substitute for metal. Some common applications for biocomposites include artificial hands and feet made from natural fibers. Hemp fiber (Boehmeria Nivea) is resistant to bacteria and fungi. Several studies related to hemp fiber as a material for prosthetic legs have been widely used compared to glass fiber. In addition, biocomposites also have the potential to be applied to implants in the body, such as bone implant plates.

Bone implant plates are generally made of stainless steel or titanium, which have the strength and toughness to fuse broken or fractured bones. However, one of the disadvantages of using bone implant plates is that the metal implant material must be imported, making it relatively expensive. Therefore, an alternative material is needed to overcome this limitation. Ultra High Molecular Weight Polyethylene (UHMWPE) plastic is a good candidate for making high-standard joint implants, as it is biocompatible with body tissue. [2].

UHMWPE is a type of polymer that has impact resistance, abrasion resistance, lubrication capabilities, and is non-reactive to chemicals. In the fields of biomedical engineering and tissue engineering, including the creation of orthopedic implants, scaffolds, surgical guides, templates, and prostheses, UHMWPE materials have been used. [3]. Characteristics of compatibility with the original trabecular bone network indicate that it can be used effectively in implant procedures. UHMWPE composites have several properties, including friction coefficient, wear resistance, elastic modulus, strength [4].

UHMWPE material has been used in bearings in arthroplasty and cartilage repair. [5], implant with wound healing and antimicrobial properties [6], craniofacial and maxillofacial applications [7]. Abduladim Saleh Salem & Bala [8] Using PP/UHMWPE as a biomaterial composite to create implants for restoring large skull bone defects. Experimental studies revealed that a 10% UHMWPE incorporation resulted in a 57% increase in impact strength, a 17.9% increase in biocompatibility, and a 9.6% increase in thermal stability.

Based on the above background, with the impact toughness of composites with variations in fibre reinforcement composition of 3%, 5%, and 7% in the Ultra High Molecular Weight Polyethylene (UHMWPE) matrix, it is hoped that this can be used as a biocomposite material for application in body implants.

2. Material and Method

The research method used was experimental research to determine the effect of adding material mixtures, under controlled conditions in the manufacture of composite specimens by varying the volume fraction of composite fibers. The composite molding results were formed in accordance with the ASTM D5942 standard for impact testing. The data analysis technique in this study used descriptive data analysis, which described the research results in graphs and tables.

The research procedure consists of several procedures and processes, namely a literature study by gathering information from books, journals, and articles, sample preparation beginning with the preparation of hemp fiber material that is treated with 5% NaOH for 2 hours and then formed into 2-3 mm pieces and UHMWPE in the form of 80 mesh particles. specimen preparation using the hot press method with variations in the composite volume fraction consisting of hemp fiber (SR) and UHMWPE (UP) at variations of 3%SR: 97%UP, 5%SR: 95%UP, and 7%SR: 93%UP, impact and SEM testing on specimens, and analysis of test results.

2.1. Hemp Fiber

Hemp fiber (Boehmeria nivea) is obtained from the stems of the plant. The hemp plant has a tall, slender, straight stem, approximately 1.5–2.5 metres in height and 1.25–2 mm in diameter. Hemp fiber is characterised by its shiny white colour, which does not fade in sunlight, and its resistance to bacteria and fungi. Hemp fiber is brittle, making it suitable for use in nets, canvas and rope [9]. The properties of hemp fiber can be seen in Table 1.

Table 1. Properties hemp fiber

No	Characteristics	Hemp Fiber
1.	*Average ultimate fibre length (mm)*	120-150
2.	*Average ultimate fibre diameter (μ)*	40-60
3.	*Tensile strength (kg/mm^2)*	95
4.	*Moisture regain (%)*	12
5.	*Cellulose*	72-97
6.	*Lignin*	1-0
7.	*Hemicellulose, pektin, etc*	27-3

2.2. *Ultra High Molecular Weight Polyethilene* (UHMWPE)

UHMWPE is a polymer that has impact resistance, abrasion resistance, is lubrication-friendly and is non-reactive to chemicals. [3]. UHMWPE has low flowability and high viscosity due to its high molecular weight. When heated beyond its melting point, it does not melt but becomes flexible like rubber [10]. The properties of UHMWPE can be seen in Table 2 [11].

Table 2. Properties UHMWPE

No	Characteristics	UHMWPE
1.	*Melting temperature (ºC)*	132-138
2.	*Molecular weight (10^6 g/mol)*	3,5-7,5
3.	*Specific gravity*	0,925-0,945
4.	*Poisson's ratio*	0,46
5.	*Modulus elasticity (GPa)*	0,5-0,8
6.	*Tensile ultimate strength (MPa)*	39-48
7.	*Tensile yield strength (MPa)*	21-28
8.	*Tensile ultimate elongation (%)*	350-525
9.	*Degree of crystallinity (%)*	39-75
10.	*Impact strength (J/mm^2)*	1070
11.	*Wear rate (mm^3/10^6 cycles)*	80-100
12.	*Density (g/cm^3)*	0,945

2.3. Treatment of Hemp Fibres

Hemp fiber is used as a reinforcing material in composites. The hemp fiber is treated with a 5% NaOH solution and soaked for 2 hours. This process is carried out to remove fibre components that can reduce interfacial strength, namely hemicellulose, lignin, or pectin. [12]. The NaOH treatment is followed by a neutralisation process using running water until the NaOH layer is completely removed. The hemp fiber are dried for approximately 4-5 hours under the hot sun.

2.4. Specimen Preparation and Testing

The impact test specimens referred to ASTM D5942 standard are shown in Figure 1.

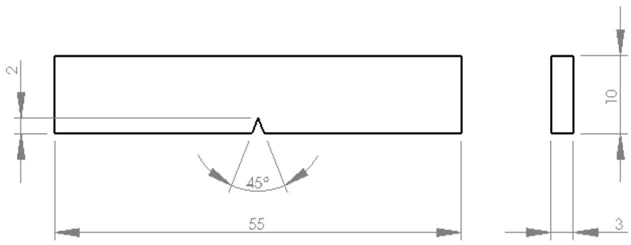

Figure 1. ASTM D5942 Standard

The specimen was pressed using a hot press method with a pressure of 100 kg, a temperature of 215°C, and a holding time of 30 minutes [13] with random hemp fiber orientation. The volume fraction comparison used was Hemp Fiber (SR) with UHMWPE matrix (UP) using three types of mixtures, namely 3% SR: 97% UP, 5% SR: 95% UP, and 7% SR: 93% UP.

The testing was conducted at the materials testing laboratory of Sanata Dharma University in Yogyakarta. The impact testing apparatus used a Charpy impact tester with an arm length of 0.3948 m and a pendulum weight of 1.357 kg. The testing was conducted at the materials testing laboratory of Sanata Dharma University in Yogyakarta.

3. Results and Discussion

The impact test specimens are shown in Figure 2. Each test sample was prepared in accordance with ASTM standards and measured using calipers prior to testing.

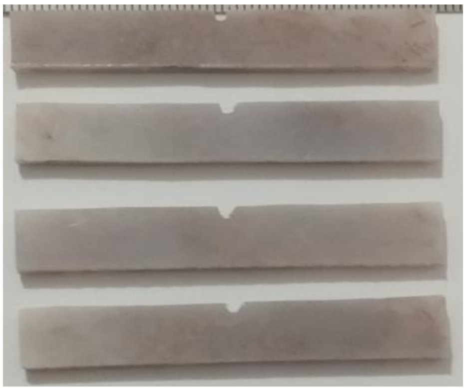

Figure 2. Impact Test Specimen

3.1. Impact Test Results

Impact testing aims to determine the toughness value of a specimen when subjected to sudden loading through impact. The basis of impact testing is to determine the absorption of potential energy from a load pendulum swinging from a certain height and angle, then striking the test object, causing the test object to deform. The average impact resistance value can be seen in Figure 3.

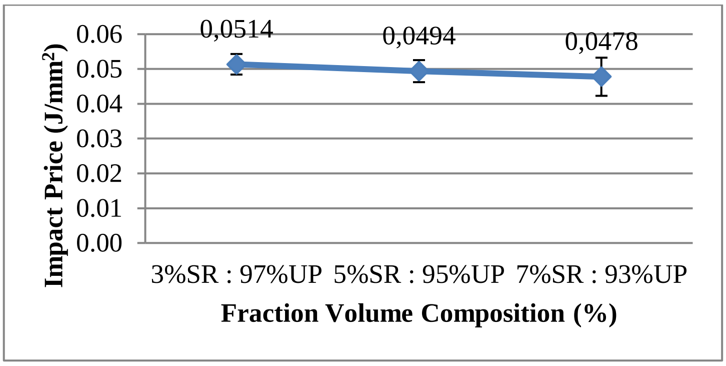

Figure 3. Average impact resistance value

The volume fraction variation of 3%SR:97%UP with 5%SR:95%UP experienced a decrease in impact value of 0.002 Joules/mm², and between the volume fractions of 5%SR:95%UP with 7%SR:93%UP, the decrease was 0.0016 Joules/mm². The average impact value did not differ significantly because the same matrix, UHMWPE, was used. A decrease in the fibre volume fraction can increase the impact toughness value of jute fibre composites with a UHMWPE matrix in withstanding pendulum loads. Relevant to research on HDPE composites and cantula fibres, it is shown that the greater the amount of HDPE powder, the more optimally it can bind the cantula fibres, thereby increasing the impact toughness of the composite. [14].

3.2. *Scanning Elektron Microscopy* (SEM) Test Results

Observation of the fracture of the impact test specimen was carried out using a SEM testing device, as can be seen in Figure 4. The fracture cross-section shows that there was fibre pull-out failure, debonding, and matrix cracking. Fibre pull-out occurs when the fibres in the composite are pulled out of the matrix during testing, caused by an imperfect bond between the matrix and the fibres. Debonding occurs when there is separation between the fibres and the matrix or between layers within the composite, caused by adhesive failure. Matrix cracking occurs due to low-speed impact events, followed by matrix stress, compression, and shear. This is relevant to the research by Mulyo & Yudiono. [15] stating that the pendulum load was well absorbed by the bond between the fibres and the matrix, resulting in fibre pull-out, which occurred due to the weak bond between the fibre interface and the matrix, thereby reducing the impact toughness value.

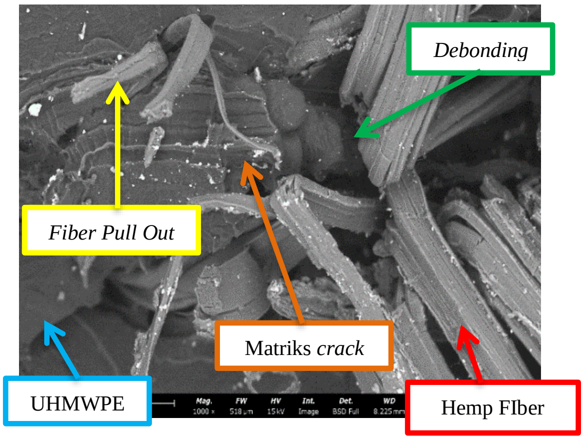

Figure 4. Cross-section photo of impact test fracture

4. Conclusion

Based on the results of research on the variation of the volume fraction of hemp fibre and UHMWPE plastic composites on impact toughness and SEM, it can be concluded that the hemp fibre volume fraction with a UHMWPE matrix has the highest impact toughness in the 3%SR : 97%UP variation, which is 0.0514 J/ mm^2, and the lowest is found in the 7%SR : 93%UP variation, which is 0.0478 J/mm^2. From these results, it can be concluded that the more flax fibre volume there is, the lower the impact toughness value will be, and conversely, the more UHMWPE matrix volume there is, the higher the impact toughness value will be.`The results of SEM testing of fracture cross-sections from impact testing show that there is failure in the fracture cross-section due to fibres in the composite being pulled out of the matrix (fibre pull-out), and separation between the fibres and the matrix or between layers in the composite, caused by debonding.

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