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Composite Manufacturing of Recycled Polypropylene Fiber-Reinforced Epoxy Made of Medical Mask Waste

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ABSTRAK

Dengan maraknya penggunaan masker sekali pakai, maka limbah dari masker tersebut menjadi polemik di tengah masyarakat karena masker terbuat dari bahan yang sama dengan plastik yang tidak mudah terdegradasi. Oleh karenanya, perlu pengolahan limbah tersebut untuk menjadi produk baru salah satunya menjadi komposit. Penelitian ini bertujuan untuk menghasilkan komposit dari resin epoksi dan lapisan tengah masker medis untuk mengetahui bagaimana pengaruh penambahan fraksi volume bagian lapisan tengah masker medis terhadap kekuatan tarik dan mengetahui sifat, struktur, dan karakteristik pada komposit lapisan tengah masker medis. Karena komposit merupakan gabungan dua bahan atau lebih yang disusun untuk meningkatkan sifat mekanik bahan agar lebih unggul dan memiliki sifat yang tidak sama dengan sifat bahan aslinya. Pemanfaatan material komposit pada saat ini semakin berkembang, seiring berjalan dengan meningkatnya penggunaan bahan yang lebih unggul tersebut yang semakin meluas mulai dari yang sederhana seperti alat-alat rumah tangga sampai dalam bidang industri otomotif. Pengolahan masker medis terutama lapisan tengah masker medis pada penelitian ini berupa lembaran polipropilen yang telah disterilisasi dan dipotong-potong dicampur dengan resin epoksi sebagai fasa pengikat dengan perbandingan fraksi volume 1:3 pada sampel 1, 1:1 pada sampel 2 dan sedangkan sampel 3 adalah 3:1. Kemudian pengujian dilakukan secara fisik dan mekanik, yaitu pengamatan morfologi menggunakan *Scanning Electron Microscope* (SEM) serta uji kekuatan tarik. Berdasarkan hasil uji tarik bisa diamati rata-rata tegangan maksimum setiap volume serat polipropilen pada 25% sebesar 1,73 MPa, 50% sebesar 2,58 MPa serta 75% sebesar 19,64 MPa. Hasil tersebut dapat disimpulkan bahwa semakin besar persentase volume serat polipropilen yang berasal dari masker maka akan semakin besar pula nilai tegangan maksimum yang diperoleh.

Keyword:

medical mask; composite; volume fraction; stress; polypropylene

ABSTRACT

With the widespread use of disposable masks, the waste from these masks has become a polemic in the community because masks are made of the same material as plastic, which is not degradable. Therefore, it is necessary to process the waste to create new products. One of them is a composite. This study aims to produce a composite of epoxy resin and the middle layer of a medical mask to determine the effect of adding the volume fraction of the middle layer of a medical mask to the tensile strength and to determine the properties, structure, and characteristics of the composite middle layer of a medical mask. Because the composite is a combination of two or more materials that are arranged to improve the mechanical properties of the material, it is superior and has properties that are not the same as the properties of the original material. The use of composite materials is currently increasing, as is the use of these superior materials, which are becoming more widespread in applications ranging from simple household appliances to the automotive industry. Processing of medical masks, especially the middle layer of medical masks, was studied in the form of polypropylene sheets that had been sterilized and cut into pieces mixed with epoxy resin as the binding phase with a volume fraction ratio of 1:3 in sample 1, a ratio of 1:1 in sample 2, and a 3:1 ratio in sample 3. Then the tests were carried out physically and mechanically, namely morphological observations using a scanning electron microscope (SEM) and tensile strength tests. Based on the results of the tensile test, it can be observed that the average maximum stress for each volume of polypropylene *fiber is 1.73 MPa at 25%, 2.58 MPa at 50%, and 19.64 MPa at 75%. These results indicate that the greater the volume percentage of polypropylene fiber originating from the mask, the greater the maximum stress value obtained.*

1. INTRODUCTION

Before the widespread use of surgical masks during the COVID-19 pandemic, polypropylene was the second-largest plastic waste after polyethylene. In 2019, 10 million metric tons of polypropylene were sold, and by 2020, sales of recycled goods had reached $72,6 billion, with recycled polypropylene accounting for 4%, or 2.9 billion dollars [1]. As a result, while the act of recycling polypropylene is very common, the raw materials of recycled polypropylene are still primarily derived from plastic bottles and shopping plastics. Several studies have recycled polypropylene both as a pure raw material and with waste mixtures. The studies of Galve et al. (2019) and Vidakis et al. (2021) have tested the recycling of pure polypropylene waste or 100% polypropylene without any additional materials or impurities. Meanwhile, some studies used a mixture of polypropylene with polyethylene terephthalate (PET), LDPE, and HDPE [2]–[5]. Raw polypropylene and recycled polypropylene can be applied by injection for additional parts in industrial tools. Recycled polypropylene has good dimensional stability and processing capability, so it can replace raw polypropylene to reduce waste [6]. Polypropylene can be recycled many times, and although its tensile strength will decrease due to pressure and heat during extrusion, its flexural strength will increase, even up to six times its impact strength is still considered normal [1], [2]. Meanwhile, research using polypropylene with the addition of other plastic waste such as HDPE and LDPE produces properties that are almost the same as pure recycled polypropylene, whose applications can be used for bottles, containers, folding tables, pipes, and crackle bags [3], [5]. This study is also in line with previous studies showing that polypropylene mixtures using additional PET plastic waste can also be produced into pipes that can compete with commercial pipes if they are efficiently mixed [4], [7], [8]. Besides HDPE and LDPE, which are used as resins for polypropylene fiber-based composites, epoxy is also applied in some studies. The chemical inertness of polypropylene does not match with the epoxy matrix [9], since the polypropylene is thermoplastic while the epoxy is thermoset. But the researchers have overcome the problem by modifying the surface of polypropylene with a mixture of mercapto-modified ethylene–vinyl acetate copolymer, which resulted in an outstanding impact characteristic as compared to pure polypropylene fiber-based composites [9]. The impact strength improved from 259 J/m to 951 J/m. The polypropylene fibers were blended for composite with epoxy resin with a concentration of 5, 10, or 15 wt % [10], but this research only investigated the thermal degradation without any mechanical tests. Another way to make a composite out of polypropylene/epoxy was through the pyrolysis of polypropylene waste, then the result was cured with epoxy resin [11]. 10% of polypropylene had the highest tensile strength compared to 30% and 50%, with 90-100 MPa, while the percentage of 50% of polypropylene fiber and epoxy in another study obtained 28 MPa of tensile strength [12]. The earlier studies also used waste from medical masks to calculate the mechanical properties of a thin layer of polypropylene sheet [13], [14]. On the other hand, there aren't many composite samples that have been investigated with the raw materials from medical mask waste.

From the literature review above, previous research has several shortcomings that this research will contribute to. They are: previous research had used polypropylene from plastic bottles but had not used non-woven polypropylene or polypropylene waste from medical masks. Concerning the shortcomings of previous research, this study aims to contribute by testing polypropylene from a three-layer medical mask, in which all layers are made of polypropylene. The epoxy resin was used as a matrix to bind the fiber reinforcement without heat treatment for curing the composite. It was chosen to make it easier for the community to produce a composite while using less energy and recycling the waste of medical masks. By combining these two materials, the study is expected to obtain the characteristics of a PP/epoxy composite for further application to the composite-based product.

2. MATERIALS AND METHODS

2.1 Materials

The materials that were used in this study are polypropylene fibers obtained from medical masks (shown in Figure 1) produced by PT. Wei Kang Medical; epoxy and hardener, which were purchased from Nusakimia.

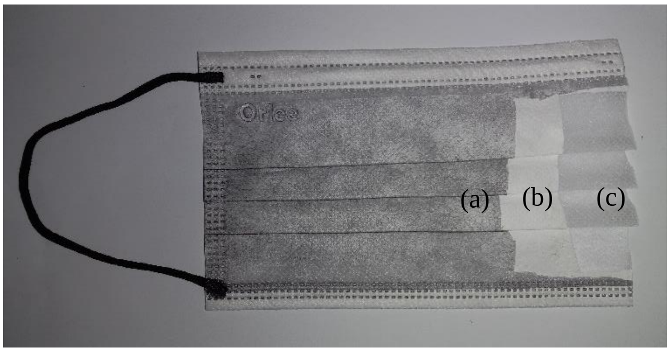


Figure 1 Specimen of a medical mask with (a) outermost layer, (b) middle layer, and (c) innermost layer

2.2 Preparation Process for Making Composite Samples

The middle layer mask material, which is shown in Figure 1 (b), was weighed at 150 grams and cut into a rectangular shape. The middle layer medical mask was chosen because it is made of the strongest polypropylene layer, as opposed to the first and third layers, which are suitable for composite materials. It was known that the mask was made of polypropylene as the result of an FTIR investigation from the earlier study conducted by the researcher [13]. After being cut, the mask material was put into a grinder for a maximum of 10-15 grams to be smoothed evenly to produce reinforcement in the form of particles. According to some studies, the smaller the particles, the higher the strength and hardness of the composite [15]–[17].

(a) (b)

Figure 2 Specimen Preparation (a) before and (b) after being grinded

The resin was put into a beaker, and the hardener was added in a ratio of 2:1. After that, the two ingredients were stirred until homogeneous for 5 minutes, and then the reinforcement was added with a composition of 25%, 50%, and 75%, and stirred until the composite solution was homogeneous for 5 minutes. The mixture was poured into the mold and flattened with a rack before being pressed with ballast or a press for at least 12 hours at room temperature (20–25°C) with 50% humidity (Rh). After waiting for the curing process, the composite was cut according to ASTM D 638.

2.3 Tensile Test

Tensile strength was measured using a Universal Testing Machine (UTM). Samples were tested for thickness, width, and initial length of the sample according to ASTM D 638 [18]. The ends of the two composite samples were clamped on a tensile testing machine, and the results of the first time the composite broke were recorded, namely the Pmax and ΔL values. Each sample was repeated three times, and the average was calculated.

Figure 3 Specimens for Tensile Tests

2.4 SEM (Scanning Electron Microscopy)

The analysis was carried out using a scanning electron microscope (SEM). The samples were prepared in clean and dry conditions, then cut with a saw following predetermined testing standards. The test samples were cut into 1 cm x 1 cm x 2 cm pieces. After that, the sample was inserted into the SEM, and morphological images were observed with a magnification of 1.000-2.000. The SEM analysis aims to observe the spread of reinforcement (polypropylene) and the matrix in the composite [3], [4].

3. RESULTS AND DISCUSSION

At a composition of 25% polypropylene, the density is very low, while at compositions of 50% and 75%, the density is getting higher. This is shown in Figure 4 (A) with a composition of 25% polypropylene, (B) with a composition of 50%, and (C) with a composition of 75%.

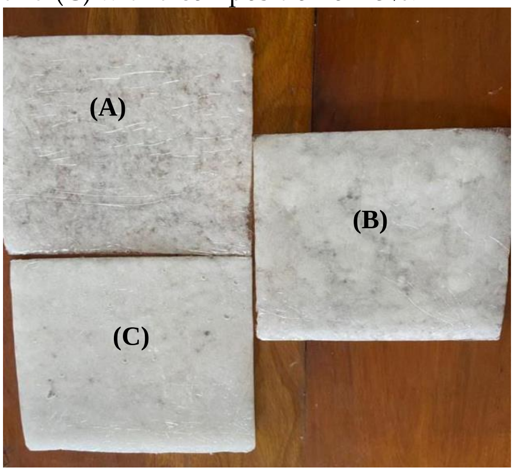


Figure 4 Fibers-reinforced composite with the composition of polypropylene in (A) 25%, (B) 50%, and (C) 75%

3.1 Tensile Test

From the tensile test data in Table 1, it is found that the maximum tensile test results were the lowest at 25% reinforcement composition by 1,73 MPa and the highest at 75% reinforcement composition by 19,64 MPa. This increase also occurred in the research of Sujita (2015) [19]. The greater the amount of reinforcement in the composite, the higher the maximum stress on the tensile strength. In this case, the middle layer (medical mask) serves as reinforcement and has strong tensile properties compared to the binder (matrix) of epoxy resin. This increase is following the existing theory where the strength of the composite increases with the addition of the reinforcement composition [20]. The concentration and distribution of the middle layer of the mask as reinforcement greatly affect the strength of the composite [21]. In addition, the small value obtained in this tensile test (stress value) is due to the process of mixing the epoxy and hardener, which is still done manually, causing voids that are also very influential on the strength of the composite. The strain, on the other hand, reached its highest value when the volume fraction of reinforcement was 50%. The maximum load that can be held by the samples is shown in Figure 5. It presents that the specimen with 75% of fiber has the highest number of loads that could be applied, which was 2,02 kN or 2.020 Newtons.

Table 1 Stress and Strain of the composite

Sample ID	Percent of Reinforcement	Stress (MPa)	Strain (%)
A	25%	1,73	93,01
B	50%	2,58	174,94
C	75%	19,64	9,92

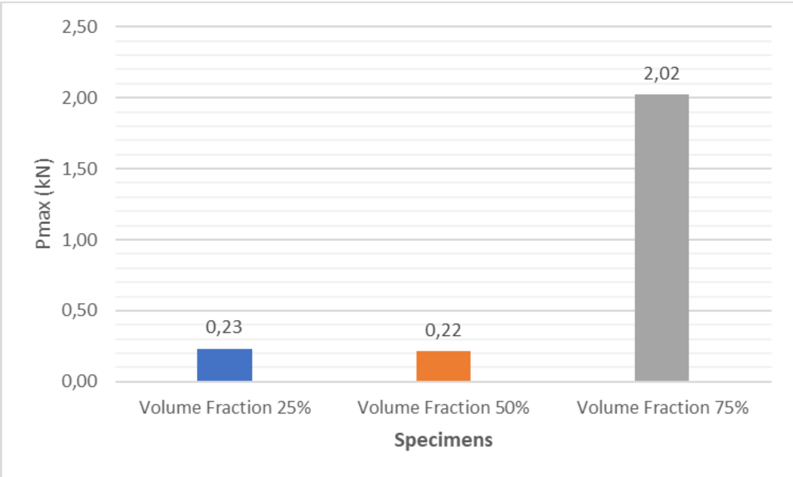
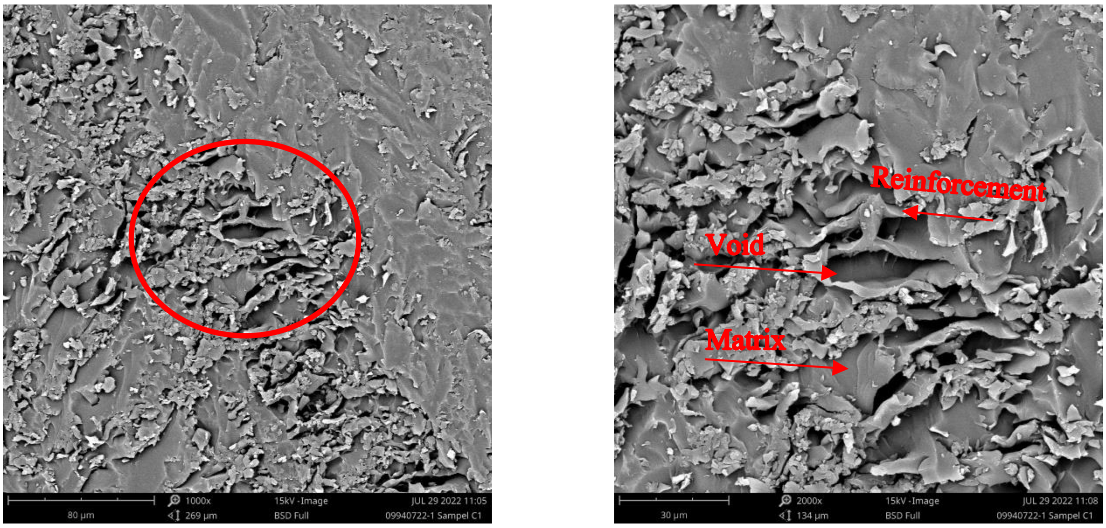


Figure 5 Graph of Maximum Load Average of Composite

3.2 SEM (Scanning Electron Microscopy)

This SEM analysis was carried out after testing the tensile strength in the tensile fracture area of the epoxy composite reinforced with the middle layer of medical masks with the highest tensile strength value, namely the 75% reinforcement volume fraction. This test aims to find out how the bonding appearance between the middle layer of medical masks is reinforced with epoxy resin as a binder (matrix). The tensile test sample was cut according to the SEM test standard and then used as an SEM observation sample. The adhesive strength of a composite affects the strength of the composite to withstand a given load.



(a) (b)

Figure 6 SEM image at (a) 1000 times of magnification and (b) 2000 times of magnification

Figure 6 above shows the SEM results of a composite sample with a 75% reinforcement volume fraction of the middle layer of a medical mask. Based on the picture, the morphological state of the sample can be seen. The SEM image shows that the middle layer of the medical mask mixed well with the epoxy resin matrix, but the maximum stress was still low. This is due to a weak bond between the matrix as a binder and the middle layer of the medical mask as reinforcement. It might have occurred because there are still visible air voids (voids) in the material. These voids can affect the strength of the composite.

4. CONCLUSION

The addition of a middle layer mask as reinforcement can increase the tensile strength of the polypropylene/epoxy composite. The study used no heat treatment to cure the composite, thus it could be easily applied by the community to produce a composite for occasional application while also taking advantage of recycling the waste of medical masks. The highest overall tensile strength is found in the 75% reinforcement composition, where the tensile stress is 19,64 MPa. The lowest tensile strength is found at 25% reinforcement, where the tensile stress is 1,73 MPa. The uneven distribution of reinforcement affects the strength of the composite. Further research related to composites can be developed with resin materials and materials other than those used in this study at different temperatures or pressures for the manufacture of composites. Examples of other alternatives to epoxy resin substitutes are polyester, phenolic, polycarbonate, etc. This aims to determine the different effects of each material on the sample.

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