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Tensile Strength and Density Evaluation of Composites from Waste Cotton Fabrics and High-Density Polyethylene (HDPE): Contributions to the Composite Industry and a Cleaner Environment

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This article contributes to:

Highlights:

- The composite characteristics of the waste cotton fibers and HDPE were studied
- It was found that volume fraction of cotton fiber and the elasticity of HDPE are interdependence
- Composite from waste cotton fibers and HDPE is appropriate for light-duty products and contributes to a better environment

Abstract

The growth of the textile industry and the massive use of plastic-based materials create economic growth, but it produces waste from post-use, such as clothing waste from cotton fabrics and HDPE that can be recycled and combined as composite materials. Therefore, an experiment was carried out to investigate and analyze the effect of the fiber volume fraction of waste cotton fabric (1.5%, 3.5%, 4.5%, 6%, and 7.5%) with straight fiber arrangement on the tensile strength and density. From the test results, a tensile strength of 178.4 MPa and 182.6 MPa was obtained for yield and max stress, respectively at a fiber volume fraction of 7.5%. Meanwhile, the highest density of 0.95 g/cm^3 was obtained at 1.5% fiber volume fraction. The fracture macroscopic view of the specimen shows a resilience fracture (uneven and appears stringy). Although the strength of this composite cannot yet compete with the new composite material, it has a decent environmental contribution. Considering the availability of waste cotton fabrics and HDPE, it promises to be produced as a low-strength composite for construction, ornamentation, or coatings.

Keywords: Composites, Waste cotton fabrics, Waste HDPE, Low strength composites

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1. Introduction

In the last few decades, the attention to material recycling has increased rapidly, including composites which are now widely used in the world, for example for car compartment applications, construction, aerospace, and packaging. Composite materials from waste reduce environmental burdens and create new circular economies [1]–[4]. The growth of clothing industry contributes to economic sector both domestically and globally, but it creates new environmental problems [5]–[12]. Illustration of waste from textile and HDPE products is presented in Figure 1. The problem is not only present during the production process but also after product usage, such as the presence of waste from textile products [13]–[15]. On the other hand, waste from textile products is a serious problem for environment, it has potential to be recycled as a reinforcement of composite materials with appropriate polimer matrixs [16]–[18].

Figure 1. Illustration of waste from textile and HDPE products: (a) captured from The Times [19] and (b) capterued from ScienceNews [20]

The polymers for composites are generally from thermosets, however, they are non-biodegradable and non-recyclable. One of the polymer materials that can be recycled is high-density polyethylene (HDPE) [21], [22]. HDPE is also a hard and scratch-resistant polymer, making it suitable for static construction. Meanwhile, considering its properties, HDPE waste is a potential matrix candidate. Therefore, the incorporation of cotton fiber from textile product waste and HDPE waste is expected to be a solution to reduce environmental burdens, as discussed earlier, into a new useful composite material.

Research on HDPE composites has been widely reported with the potential for unique new properties. Ning [23] conducted research on natural fibers from kenaf as HDPE reinforcement. As a result, the tensile strength of kenaf-HDPE composite was 49 MPa. Further investigation on microscopic view, a lot of kenaf fibers were pulled out during the test, although on macro-photos, kenaf and HDPE fibers seemed homogeneous. Another study was conducted by Mendes [24] who investigated bagasse fiber with HDPE matrix. The combination of bagasse with HDPE matrix produces a low tensile strength, even lower than the tensile strength of HDPE itself. The highest tensile strength at 20% sugarcane bagasse fiber content is 7.7 MPa, while the comparison is HPDE with a maximum tensile strength of 24.1 MPa.

The use of other plastic waste was also investigated by Abdullah [25]. He researched the fiber of kuang leaf to strengthen recycled polypropylene. The leaf fibers were treated with and without NAOH immersion. As a result, the untreated polypropylene-leaf fiber composite had a tensile strength of 15.6 MPa, lower than polypropylene strength value of 18.1 MPa. However, the fiber treatment can increase tensile strength up to 23.1 MPa. Another research on plastic waste was conducted by Ejiogu [26]. He conducted research on coconut husk fiber to strengthen polypropylene waste. A mixture of 50-100% waste polypropylene can increase the tensile strength up to 30 MPa. Meanwhile, the addition of coconut husk fiber (50, 60, 70, 80, 90%) to the matrix increased the polypropylene strength by 33, 34, 35, 36, 40 MPa, respectively.

2. Material and Methods

This study used waste cotton fabrics and HDPE matrix with volume fractions of 1.5%, 3.5%, 4.5%, 6% and 7.5%. Cotton fiber is taken by breaking it from used clothes and HDPE waste is crushed using a crusher machine. The chopped HDPE is melted with a stove fire in a stainless-steel container. After melting, the liquid HDPE is poured into a special mold to make specimens. Then, the test was carried out with ASTM D638-04 standard. Dimensions of the tensile test specimens are presented in Figure 2a. Density tests were also carried out with specimen dimensions as presented in Figure 2b. Specimens for density test were weighed using a scale with an accuracy of 0.01 grams and the dimensions were measured with a caliper with an accuracy of 0.02 mm.

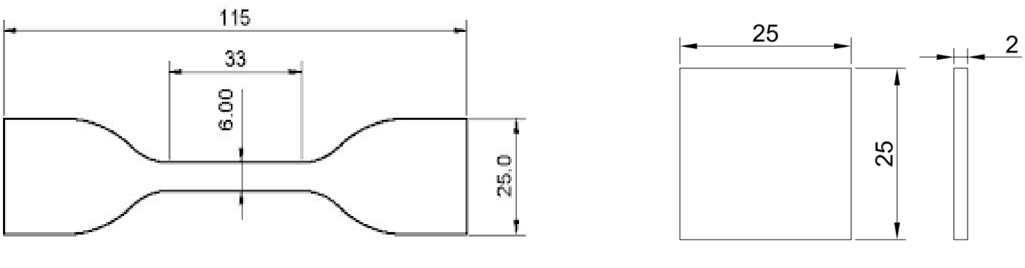


Figure 2. The specimen: (a) dimension for tensile test and (b) dimension for density test, all dimension in mm

3. Results and Discussion

3.1. Mechanical properties test

This study measures the tensile strength of single fiber and HDPE compared to cotton-HDPE composites. The result of the single fiber tensile test is presented in Table 1, where the average single fiber strength test is 60.3 MPa and the average strain is 12.6%. Furthermore, the tensile strength of the new cotton fiber is 249 MPa due to the uses of textile product waste. Then, the average results of tensile strength testing with volume fractions of 1.5%, 3.5%, 4.5%, 6% and 7.5% with straight fiber arrangement are presented in Figure 3. The lowest tensile strength was found in fiber content 1.5% of 160.83 MPa and 164.7 MPa for yield and max stress, respectively.

Table 1. Tensile test results on single fiber

Experiment	Tensile stress (MPa)	Strain (%)
1	64.0	15.0
2	60.9	13.0
3	56.2	10.0
Rate	60.3	12.6

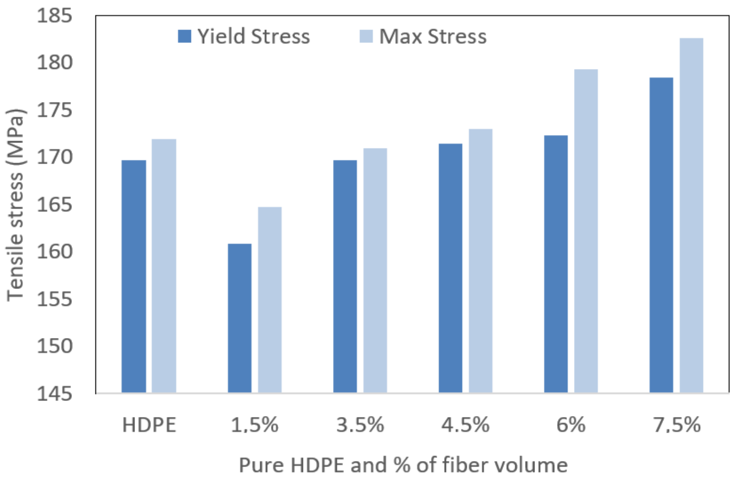


Figure 3. Comparison of tensile stress and yield stress in straight fiber arrangement

Figure 3 shows that cotton fiber significantly affects the strength of the composite. At the content of 1.5% and 3.5% the tensile strength is lower than HDPE waste, but fraction of cotton fiber increases the strength of the composite. The highest tensile strength is at a fiber content of 7.5% with a value of 161.87 MPa. However, if the fiber volume fraction is less than 4.5%, the presence of cotton fibers reduces the strength of HDPE. The volume fraction of cotton fiber and the elasticity of HDPE are interdependence. This phenomenon is explained by macroscopic view capture of the fractured specimen.

Figure 4 to Figure 9 show that resilience fractures are formed with the addition of fibers in the composite. Resilience fractures are characterized by an uneven fracture surface due to the presence of fibers. Meanwhile, on the HDPE fracture, it looks flat which shows the characteristics of a brittle fracture. The increased bonding of cotton fibers makes HDPE tougher and increases its strength. Apart from gaining strength, the addition of cotton fibers also reduces its density. To test the mechanical properties, a density test was carried out.

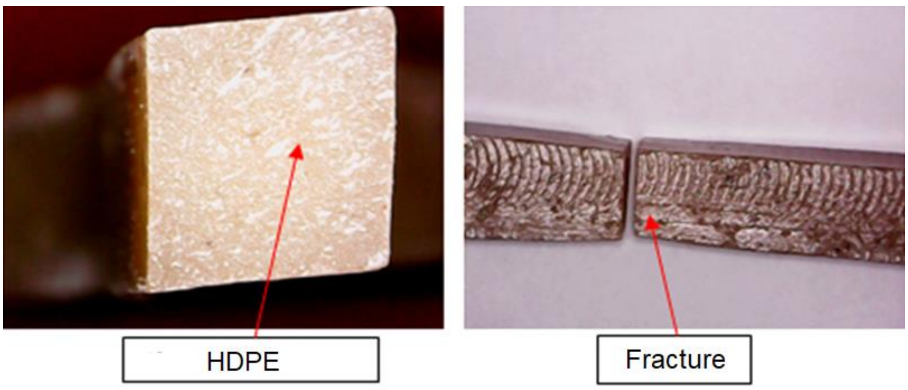


Figure 4. Macroscopic view of the HDPE fracture

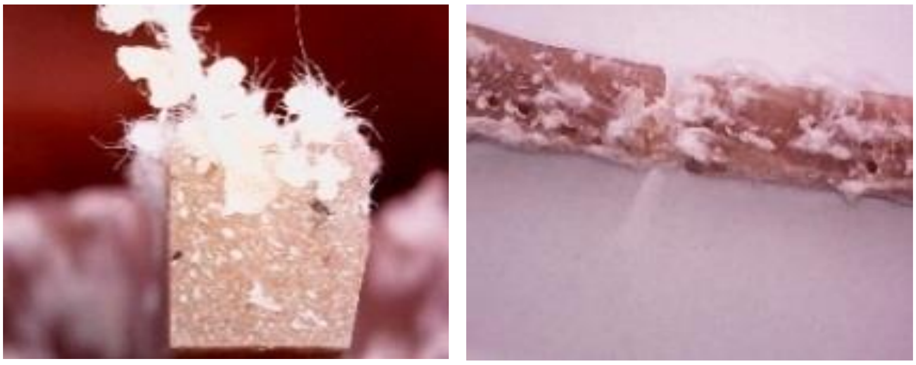


Figure 5. Macroscopic view of specimen fracture at volume fraction of 1.5% cotton fiber

Figure 6. Macroscopic view of specimen fracture at volume fraction of 3.5% cotton fiber

Figure 7. Macroscopic view of specimen fracture at volume fraction of 4.5% cotton fiber

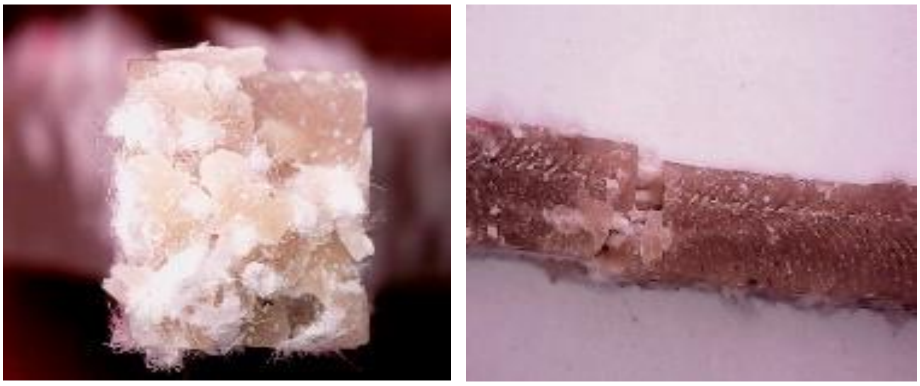


Figure 8. Macroscopic view of specimen fracture at volume fraction of 6% cotton fiber

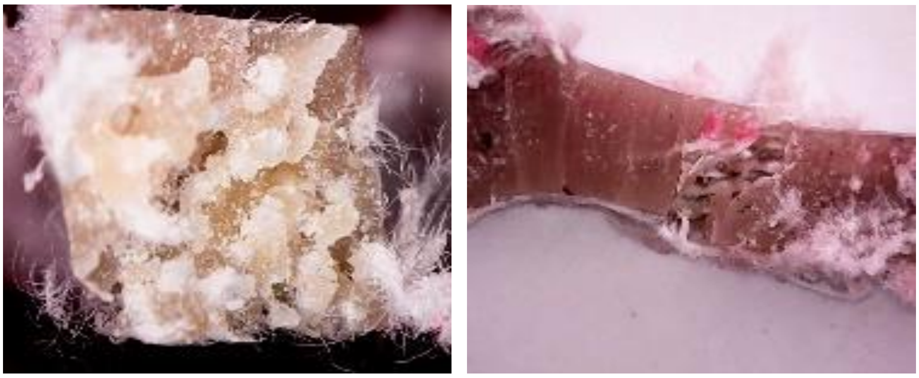


Figure 9. Macroscopic view of specimen fracture at volume fraction of 7.5% cotton fiber

Finally, the result of the density test is presented in Figure 10, where, the 1.5% fiber volume fraction has the highest density of 0.95 g/cm^3 while the lowest density is found in the 7.5% fiber volume fraction of 0.9 g/m^3. It shows that the addition of cotton fiber can lighten the composite material. For comparison, the density of HDPE is 0.965 g/cm^3 [27] and the density of cotton is 0.561 g/cm^3 [28]. Therefore, the addition of cotton fibers makes composites more competitive in terms of density.

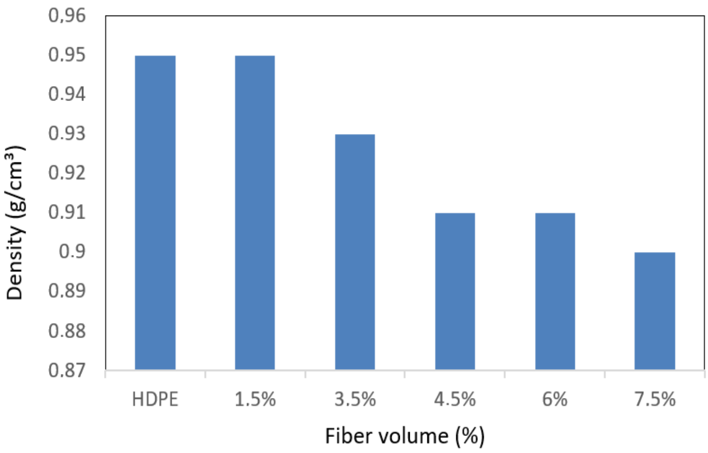
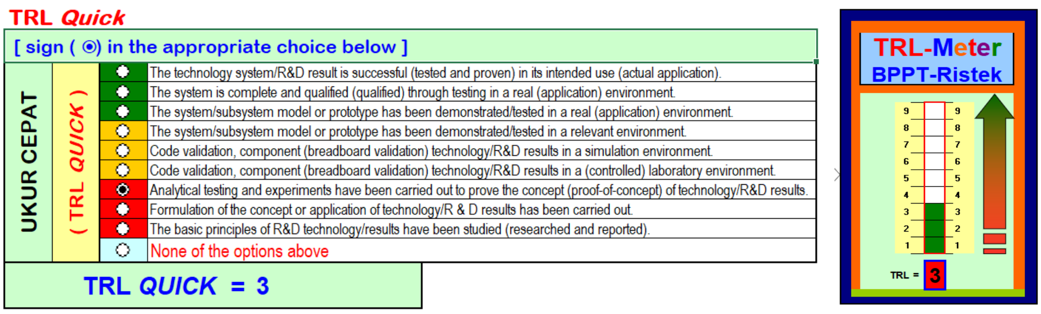


Figure 10. Density test results

Noting the discussion from ScienceNews [20], recycling a mixture of colorful HDPE bits yields a dark-colored plastic suitable solely for producing goods such as park benches and garbage bins, where colors are unimportant. Even more, only approximately 9% of the 6.3 billion tons of plastic dumped throughout the world has been recycled. Another 12% has been burnt, and over 80% has accumulated on land or in rivers. As plastic is unlikely to disappear any time soon, recycling HDPE into composites makes it easier to use for a wider range of applications. The practice of disposing of used clothes and reselling them in used clothing stores can indirectly have an impact on the environment [29]. Therefore, reusing it for reinforcing composite materials is a form of concern for the environment.

3.2. Technology Readiness Level (TRL) achievements

To measure of this finding readiness, we use a technology readiness level (TRL) measurement tool developed by the Agency for the Assessment and Application of Technology (BPPT) called TRL-meter. In principle, by looking at the properties of cotton fiber and HDPE waste, it is possible to make a composite which means that TRL-1 is fulfilled. Second, we have formulated the concept and research has been carried out, which shows that TRL-2 is fulfilled. Third, analytical testing and experiments to prove the concept has been carried out which show that TRL-3 is fulfilled. In TRL-4, it is demanded that the finding of this study has been validated in a controlled environment laboratory and this has not been fulfilled. Thus, this research achievement of TRL is TRL-3. This provides a guidance for further research, where the new composite results of this research will be continued by testing in a laboratory with a controlled environment. The results of the quick TRL are presented in Figure 11.



(a) (b)

Figure 11. TRL achievements: (a) Quick measurement and (b) Display of TRL-meter

4. Conclusion

Cotton fibers from textile waste products and HDPE combination produce competitive composite candidates for light work. From the evaluation of the tensile test, increasing the cotton fiber fraction in HDPE increased the tensile strength. The highest tensile strength results were found in the composite fiber volume fraction 7.5%. From the evaluation of macroscopic view, resilience fractures are formed by adding fiber fractions, while pure HDPE fractures form brittle fractures. The addition of cotton fiber into HDPE also reduces its density, making this composite of cotton-HDPE fiber has a potential to be industrialized. From the TRL evaluation using the TRL-meter, the technological readiness achievement of this research is TRL-3 which indicates the need for further research. Although the resulting tensile strength is lower than new materials composites, the use of waste as a composite is promising for light work construction, ornamentation, or coatings, as well as contributing to a better environment.

Authors' Declaration

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Authors' contributions and responsibilities - The authors made substantial contributions to the conception and design of the study. The authors took responsibility for data analysis, interpretation, and discussion of results. The authors read and approved the final manuscript.

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