# Optimization of tensile strength and modulus elasticity from recycled mask polymer blends

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**ABSTRACT**

This research aims to analyze the effect of differences in the proportion of recycled polypropylene (r-PP), compatibilizer, and type of mask on the tensile strength and modulus of elasticity of recycled mask product materials. The research design used in this research uses the Taguchi orthogonal L4 experimental method, which uses a quantitative approach, namely by manipulating certain conditions and providing control over the test samples. This research focused on the effect of varying the proportion of r-PP composition, maleic anhydride polypropylene (MAPP) compatibilizer, as well as varying the type of mask waste used. In this research, the composition of r-PP used was 10% and 30%. Meanwhile, the MAPP composition used is 0% and 6%. In this study, tensile testing was carried out in accordance with the American Society for Testing and Materials (ASTM) D 638 standard type V in the form of a dogbone. The results of the research show that differences in the proportion of r-PP in the composition of the polymer mixture have an effect on the tensile strength and modulus of elasticity of the recycled mask product material.



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## 1. INTRODUCTION

The spread of coronavirus disease (COVID-19) began with an incident in the city of Wuhan, Hubei Province, China, in December 2019 [1]. This has led to policies such as closing public places, including shopping centers, cinemas, restaurants, and hotels; limiting activities outside the home; and reducing or suspending public transportation, including buses, trains, ships, and planes [2]. This virus spread worldwide, including Indonesia. The public is asked to use personal protective equipment (PPE), such as medical masks, non-medical masks, face shields, and gloves, to reduce the spread of the virus [3]. Academic studies show that wearing a mask reduces the risk of infection and death [4]. While wearing a mask helps stop the spread of the virus, it also has negative environmental impacts, especially regarding microplastic pollution [5]. The unprecedented increase in mask use poses a serious threat to land and marine ecosystems [6]. Recycling used masks is a preventive measure to reduce environmental pollution [7]. The unprecedented threat posed by the use of masks requires concerted efforts to address it. Most masks are produced using polypropylene (PP) and its derivatives [6]. Although PP can be recycled due to its low viscosity, which makes processing easier [8], further efforts are needed to address the environmental impact of increased mask use. Most masks are manufactured using PP material [6]. This material is a non-degradable polymer material and is difficult to decompose in nature [9]. The mask generally consists of 3 different general parts [10]. The parts of the mask that are not made from PP are the polyester (PE) and spandex straps and the galvanized wire nose wire (NW), which is wrapped in PP. This variability is a barrier to recycling mask components [11].

Polymer blends are mixtures of two or more polymers that have been combined to produce a new material with different physical properties [12]. The advantages of mixing polymers include the development of new properties or the improvement of existing properties to meet specific needs, the reduction of material costs with little or no loss of mechanical properties, increased material processability, and the meeting of the needs of developing industries by going beyond the polymerization stage [13]. Engineered polymer and plastic blends are used in a variety of automotive applications. Polymer blending improves fuel economy in cars by reducing vehicle weight, a benefit achievable only with plastic, not metal [14]. Various biocompatible polymer blends have been prepared and used in biomedical applications. Bio-based polymer blends are always required for proper processing [15]. Miscibility is an important factor in polymer blend formation. Immiscible polymers are prone to phase separation, which can affect the mixture's surface topology and mechanical properties. There is agreement that polymer mixtures are virtually immiscible, but they can be partially miscible when admixtures are used. Compatibilizers are needed during mixing to adjust interfacial interactions, reduce interfacial tension, and achieve the required microstructure [16]. Given the distinct properties of each polymer, it cannot be ruled out that masks can serve as a base for other polymers, allowing them to be combined into a polymer blend [17]. A high-polymer blend product from mask waste can be made by adding other polymers, such as PP, polyethylene terephthalate (PET), and high-density polyethylene (HDPE). HDPE has low-temperature pressure resistance. Meanwhile, PP has low-temperature compressive strength. The temperature or melting point difference between PP and HDPE prevents the polymers from fully mixing, resulting in poor physical and mechanical properties of the polymer mixture [18].

Recycling processes, such as extrusion molding, injection molding, compression molding, stir casting, and the hot-press method, with injection molding preferred for manufacturing various products. This is because injection molding is an efficient method for mass-producing complex geometries with consistent quality [19]. Injection molding is a process of producing a product by injecting liquid plastic material [20]. Injection molding is well-suited to the mass production of complex geometries and provides consistent quality [19]. However, the complexity of injection molding makes it difficult to achieve the required quality of goods [21]. Polymer engineering, by combining two or more types of polymers, can meet requirements in various applications that homopolymers cannot [22]. Improving mechanical properties through mixed polymers has not been widely pursued and still requires further development [23]. First, mask waste must be cleaned with a disinfectant containing 70-90% chlorine-based alcohol before being processed for recycling [24]. This is then allowed to dry for 1 hour at 80 °C [7]. Polymer blend or polymer mixing is the process of mixing materials consisting of two or more different polymers, which can be carried out in liquid or solution conditions. The purpose of mixing polymers is to produce new polymers with desired properties, as well as to obtain new, unique properties from each component [13]. This method is used to create new materials with specific characteristics and applications because it is very cheap and easy to use [25].

Tensile testing is used to analyze the mechanical properties of a product by applying tensile force to determine the material’s strength. The tensile test is performed by continuously pulling the material, allowing the elongation to increase and remain constant until the material breaks. In this test, the tensile strength and elastic modulus (E) values of the material can also be obtained [26]. This test is important to know because it can serve as an average wobble quality level (AWQL) analysis of a product before it is applied in the engineering field [27]. Carrying out a tensile test aims not only to measure the tensile strength of a material but also to determine its stiffness and strain at break. In the stress-strain diagram of the tested material, there are two key pieces of information: the peak point in the linear region indicates the tensile strength, while the stress-to-strain ratio in the same region reflects the Young's modulus or E. Young's modulus indicates a material's ability to maintain its shape under applied force; stiffer materials have higher E values, indicating greater resistance to axial deformation [28].

## 2. RESEARCH METHOD

### 2.1. Method and materials

The research design uses the Taguchi orthogonal L4 experimental method, which employs a quantitative approach by manipulating specific conditions and controlling the test samples. This research focused on the effects of varying the proportion of recycled polypropylene (r-PP) composition and the maleic anhydride polypropylene (MAPP) compatibilizer, as well as the type of mask waste used. Therefore, the compositions in this study were 10% and 30% r-PP; the MAPP compatibilizer used was 0% and 6%; and the mask types used were 3-ply and 4-ply. Table 1 shows the mass fraction of polymer blends in each specimen.

Table 1. The mass fraction of polymer blends in each specimen

| No. Exp. | r-PP (%) | MAPP (%) | Type mask |
|---|---|---|---|
| 1 | 10 | 0 | 3-ply |
| 2 | 10 | 6 | 4-ply |
| 3 | 30 | 0 | 4-ply |
| 4 | 30 | 6 | 3-ply |

### 2.2. Preparation of materials

Treatment of disposable masks is based on previous research. This is done because disposable mask waste is at risk of viruses and bacteria; it needs to be handled properly. Collect previously collected disposable mask waste. Before processing, the mask is sprayed with alcohol to disinfect any remaining viruses or bacteria. Wash the disposable mask with detergent, then dry it in the sunlight. Using water and detergent during the sterilization process can maintain a filtration efficiency of 54%. Separate the components in disposable masks: face mask (FM), ear loop (EL), and NW. The FM is cut into squares measuring 10-20 mm so it can be mixed using an extruder. The polymer blend in this research consists of disposable mask waste and r-PP. To start processing the r-PP, the PP seeds are first washed with clean water to remove any remaining dirt, then dried in the sun. Once dry, the r-PP is crushed using a crusher machine to a size of 10-20 mm.

### 2.3. Manufacturing process

After the r-PP is cut into smaller shapes, the next step is to mix the polymer blend using an extruder. The mixing process begins by weighing the composition of mask waste, r-PP, and MAPP using a digital scale according to the predetermined composition, namely (90:10:0)%; (70:30:0)%; (84:10:6)%, (64:30:6)%. The extruder machine is turned on with a screw speed of 25 rpm, with a temperature on the extruder machine of 180 °C (feeding zone), 185 °C-190 °C (transition zone), and 150 °C (final zone). The temperature used to heat the machine and the mask is set under 190 °C for 2 minutes because, if the temperature and time exceed these limits, degradation of the mask and PP can occur [29]. The melt produced after the extrusion process is then cut into 4 mm pellets to facilitate the compression molding process.

The pellets produced by the extruder are chopped with a shredder into 4 mm plastic ore. The plastic pellets are then placed in the injection machine at 180 °C-230 °C for 15 minutes, and then injected into the mold. After the polymer blend is molded using an injection molding machine, the next step is to cut the specimens to a standard size using a computer numerical control (CNC) machine, as shown in Figure 1. Usually, tensile test specimens are adjusted to existing standards; some studies use specimens conforming to American Society for Testing and Materials (ASTM) D638 Type 5, with dimensions of 63.5 mm × 9.53 mm × 3.2 mm [29].

Figure 1. CNC machining specimen

### 2.4. Mechanical test

The mechanical test, a tensile test of polymer blend specimens, was performed to measure the material’s strength and resilience. It employed the ASTM D638 type V standard, commonly used for polymer-based composites. The standard specimen size is shown in Figure 2. The tensile test was performed using a Zwick Roell 20 kN universal testing machine, with vertical withdrawal of the specimen at a speed of 5 mm/min.

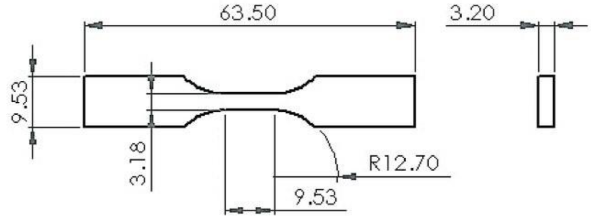


Figure 2. Tensile test specimen

## 3. RESULTS AND DISCUSSION

### 3.1. Tensile strength test result

Calculations use the Taguchi method. By using the larger-the-better response for tensile strength using (1).

$$S/N = -10Log\left(\frac{1}{n}\sum_{i=1}^{n}\frac{1}{y_1^2}\right) \quad (1)$$

Then, the results of calculating the larger-the-better signal-to-noise (S/N) ratio for tensile strength are presented in Table 2 and Figure 3.

Table 2. Calculation of S/N tensile strength ratio

| No. Exp. | Control parameters | | | S/N tensile strength ratio |
|---|---|---|---|---|
| | r-PP (%) | MAPP (%) | Type | |
| 1 | 10 | 0 | 3-ply | 29.46472 |
| 2 | 10 | 6 | 4-ply | 29.69034 |
| 3 | 30 | 0 | 4-ply | 29.64647 |
| 4 | 30 | 6 | 3-ply | 30.46131 |

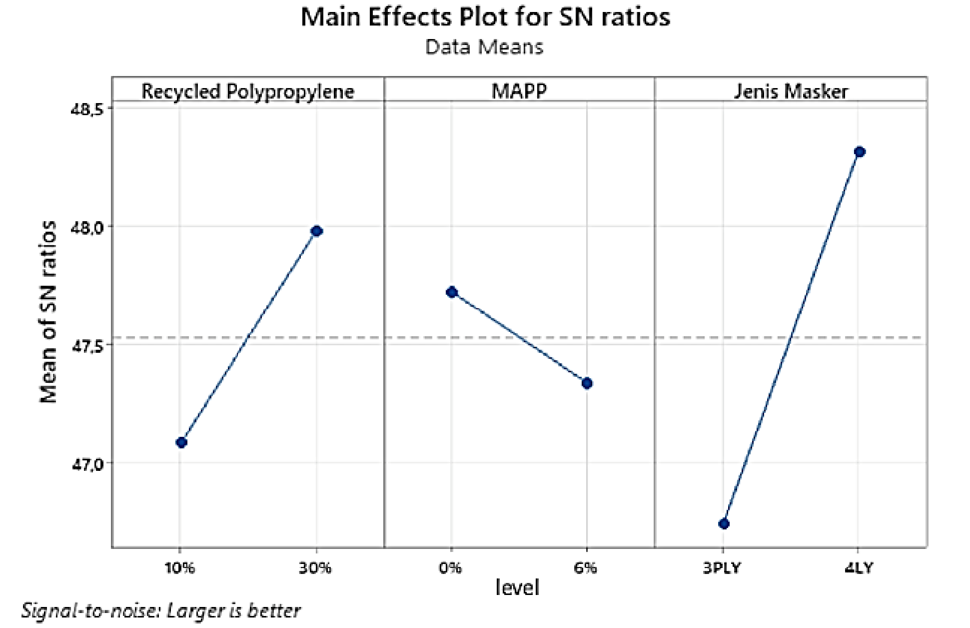


Figure 1. Plot of S/N tensile strength ratio

### 3.2. Elastic modulus test results

Calculations use the Taguchi method. By using the larger the better response for the E using (1). Then, the results of calculating the larger-the-better S/N ratio for tensile strength are presented in Table 3 and Figure 4.

Table 3. Calculation of S/N elasticity modulus ratio

| No. Exp. | Control parameters | | | S/N elasticity modulus ratio |
|---|---|---|---|---|
| | r-PP (%) | MAPP (%) | Type | |
| 1 | 10 | 0 | 3-ply | 46.4889 |
| 2 | 10 | 6 | 4-ply | 47.6769 |
| 3 | 30 | 0 | 4-ply | 48.9543 |
| 4 | 30 | 6 | 3-ply | 46.9958 |

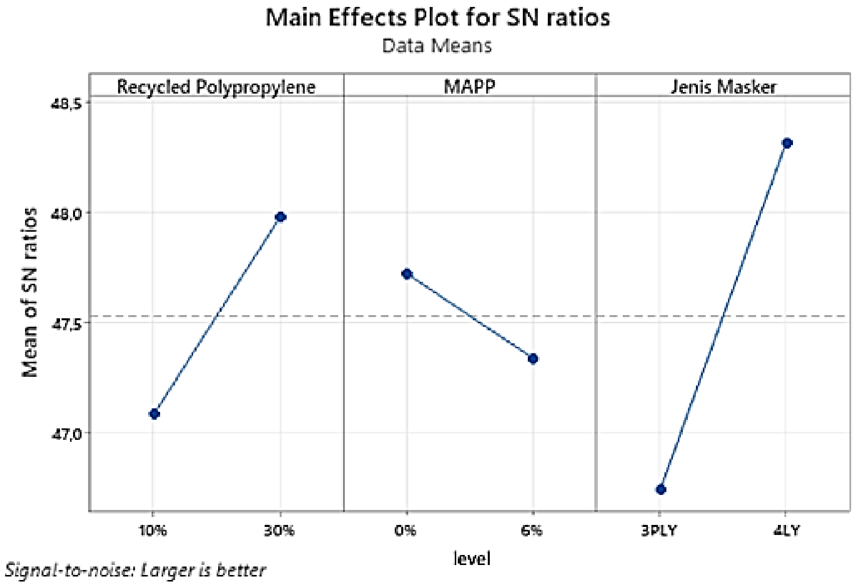


Figure 2. Plot of S/N ratio of the E

### 3.3. Analysis of variance result

Analysis of variance (ANOVA) is used to determine the influence of each parameter on the response studied. The response variable in this study was the S/N ratio, with the following factors: composition, MAPP composition, and mask type. The following is the ANOVA calculation of the S/N ratio values for tensile strength and E. The ANOVA results are presented in Tables 4 and 5, showing the influence of the parameters on the S/N tensile strength ratio, which is also processed in Minitab 19.

Table 4. ANOVA results and parameter contribution with S/N ratio on tensile strength

| Factor | Parameter | DF | Sum of square | Mean of square | Contribution (%) |
|---|---|---|---|---|---|
| A | r-PP | 1 | 0.22692 | 0.22692 | 38.83 |
| B | MAPP | 1 | 0.27064 | 0.27064 | 46.31 |
| C | Type | 1 | 0.08679 | 0.08679 | 14.85 |
| Error | | 0 | 0 | 0 | 0 |
| Total | | 3 | 0.58436 | 0.58436 | 100.00 |

Table 5. ANOVA results and contribution of parameters with S/N ratio to the E

| Factor | Parameter | DF | Sum of square | Mean of square | Contribution (%) |
|---|---|---|---|---|---|
| A | r-PP | 1 | 0.796 | 0.796 | 23.38 |
| B | MAPP | 1 | 0.1484 | 0.1484 | 4.34 |
| C | Type | 1 | 2.4751 | 2.4751 | 72.38 |
| Error | | 0 | 0 | 0 | 0 |
| Total | | 3 | 3.4195 | 3.4195 | 100.00 |

## 4. CONCLUSION

From the research that has been carried out, the following conclusions can be drawn that differences in the proportion of r-PP in the composition of the polymer mixture affect the tensile strength and modulus of elasticity of recycled mask product materials where the content of 30% r-PP produces the most optimal tensile strength and modulus of elasticity with a tensile strength value of 30.6 MPa and a modulus of elasticity value of 286.3 MPa. Differences in the proportion of MAPP in the composition of the polymer mixture affect the tensile strength and modulus of elasticity of recycled mask product materials, where a MAPP content of 6% produces the most optimal tensile strength with a value of 30.6 MPa, and a MAPP content of 0% produces the most optimal modulus of elasticity with a value of 286.3 MPa. The different types of masks in the composition of the polymer mixture affect the tensile strength and modulus of elasticity of the recycled mask product material, where the 3-ply mask type produces the most optimal tensile strength with a value of 30.6 MPa, and the 4-ply mask type produces the most optimal modulus of elasticity with a value of 286.3 MPa.

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## AUTHOR CONTRIBUTIONS STATEMENT

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C : **C**onceptualization
M : **M**ethodology
So : **So**ftware
Va : **Va**lidation
Fo : **Fo**rmal analysis
I : **I**nvestigation
R : **R**esources
D : **D**ata Curation
O : Writing - **O**riginal Draft
E : Writing - Review & **E**diting
Vi : **Vi**sualization
Su : **Su**pervision
P : **P**roject administration
Fu : **Fu**nding acquisition

## CONFLICT OF INTEREST STATEMENT

The author declares that there are no known conflicts of interest associated with this publication. There are no financial or personal relationships that could inappropriately influence or bias the content of this work.

## INFORMED CONSENT

Not applicable. This study did not involve human participants, human data, or any personally identifiable information. All data used were either publicly available, fully anonymized, or derived from non-human sources, and therefore no informed consent was required from individuals.

## ETHICAL APPROVAL

Not applicable. This research did not involve human subjects, human biological materials, or experimental procedures on animals. The work was conducted solely on computational models, publicly available datasets, or non-sensitive data that did not require intervention with living organisms. Therefore, ethical approval from an institutional review board or animal ethics committee was not necessary for this study.

## DATA AVAILABILITY

Derived data supporting the findings of this study are available from the corresponding author, [IW], upon reasonable request.

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