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# Investigating Mechanical and Wear Properties of CaCO3 Filled PP Composite Filament Production for 3D Printer

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**Abstract**

Recently, the interest in 3D printers, which is one of the polymer-based material production methods, and the amount of production in the sector are increasing day by day. It is clearly seen that 3D printers, which were used as hobby devices in the beginning, have evolved from being hobby devices to industrial production devices. When current studies are examined, it is clearly observed that not only pure polymers, but also composite materials are used in 3D printers. In this study, Pure PP and various weight filling ratio CaCO3 filled PP composite filaments were produced. Wear test and three-point bending test specimens were produced by 3D printer. When the mechanical test results were examined, it was determined that the flexural strength of the composite samples was affected adversely. The wear test results showed that the particle reinforcement reduced the friction coefficient by making a lubricating effect on the surface. The wear volume of the composite samples decreased by approximately 40% compared to pure PP. As a result, it has been seen that composite samples can be produced with some compromise in strength in applications requiring high wear resistance and low friction. Especially when it is considered that there is a ratio of approximately 1/10 between the prices of matrix and reinforcement materials, composite filament gains more importance in order to reduce the cost of the final product.

## 1. Introduction

The method of manufacturing with 3D printing, which initially appeared as a fast model production and design method, has found a large area of use for hobby purposes. However, the increase in the usage area of the produced products necessitated the production of stronger end products. [1-5]. The continuous development of 3D printing production technology has resulted in a significant increase in production speed, quality, and production reliability. However, the need for the production of structural parts and the use of high-quality materials has emerged [6,7]. While the production with 3D printer technology was initially carried out with pure and easy to produce polymers, the use of engineering polymers and composite materials was needed over time [1]. In this way, it was ensured that a product with higher properties was obtained. When current literature studies are examined, it is noteworthy that there are very few studies on composite filament production and its production in 3D printers [8,9].

One of the most widely used particle for polymer reinforcement is Calcium carbonate ($CaCO_3$). There is much more study on the effects of $CaCO_3$ particle filling for polymer matrix composites, and they are well-known in literature [11-14].

Polypropylene (PP) is one of the most popular thermoplastic polymers, with a wide area of use in industrial applications due to its lower price, high impact resistance and ductility, resistance to water and chemicals. Moreover, being recyclable and easy to process is among the main reasons that increase the interest in polypropylene. Due to the above-mentioned advantages, polypropylene is increasingly used in many application areas such as automotive,

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home furniture and appliances, toy industry, storage tanks, food packaging, medical equipment [16-18].

In this study, composite filaments were produced by reinforcing PP polymer with $CaCO_3$, which is one of the traditional particle reinforcements, at different weight rates (0, 1, 2, 4 wt%). The produced filaments were used in sample production in 3D printer and their mechanical and tribological properties were characterized. Thus, composite sample production was carried out with the up-to-date 3D technology and its applicability was evaluated in detail. It is aimed to improve the properties of the 3D printer filament with particle reinforcement and to reduce the cost of the final product.

## 2. Material and Method

### 2.1 Materials

Moplen HP500 brand name polypropylene granule was supplied from LyondellBasell Company. Filler material $CaCO_3$ particles were supplied from Omya Madencilik A.S. (Turkey). The particle used is in the average 100-250 micron size range and the optical microscope photograph is given in Figure 1.

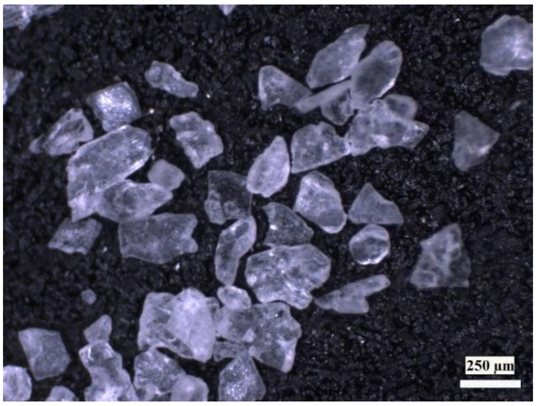


**Figure1.** Optic microscope photograph of $CaCO_3$ particle

### 2.2. Method

#### 2.2.1. Sample Preparation

Before filament production, granular PP and $CaCO_3$ particles were kept in an oven at 80°C for 24 hours to dehumidify. Retsch PM100 brand name grinder was used for mechanical mixing of $CaCO_3$ particle and PP polymer granule. Then, pure PP and different mass ratios (1, 2, 4 wt%) of $CaCO_3$ reinforced composite filaments were produced by using the Arya Tech brand extruder and wrapper shown in Figure 3. Filament production was carried out at 200°C extruder temperature. T3 Dizayn brand name 3D printer was used for sample production and printing parameters are given at table 1. 10x80x4 mm and 20x20x5 mm dimension samples were produced for bending and wear test respectively. Photos of produced samples are given at Figure 2.

**Table 1.** 3D printing parameters

| | |
|---|---|
| Nozzle Temperature | 210°C |
| Table Temperature | 100°C |
| Filling density | %100 |
| Layer thickness | 0.2 mm |
| Printing Speed | 50 mm/s |

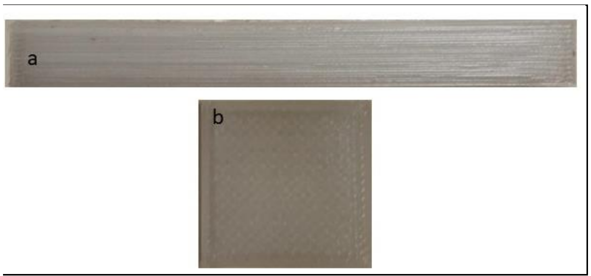


**Figure 2.** Produced test samples by 3D printer; a) 3 Point bending b) Wear

#### 2.2.2. Bending Test

3-point bending tests were applied on the samples to characterize the mechanical properties of the samples. 3-point bending tests were applied according to ISO 178 with 5 mm/min cross head speed and 64 mm span distance by Instron brand name Universal Tester.

#### 2.2.3. Wear Test

Nanovea T50 ball on disc test device was used to characterize the wear behavior of samples. ASTM G99 wear test standard was used for wear tests. Wear test parameters are given at table 2.


**Figure 3**. Flax brand name laboratory scale extruder and filament wrapper machine

**Table 2.** Test Paramaeers of Adhesive Wear Test

| | |
|---|---|
| Normal Load | 20 N |
| Velocity | 250 rpm |
| Friction Radius | 5 mm |
| Material of adhesive pin (ball) | Steel |
| Dimension of abradant ball | 6 mm |

The sample wear trace is given at Figure 4 and the calculation of the wear volume of worn surface was made according to formula (1). Here; V: wear volume, R friction radius, D: wear trace width (distance between two red lines), r: adhesive ball radius

$$V=\frac{\pi * R * D^3}{6 * r} \quad (1)$$

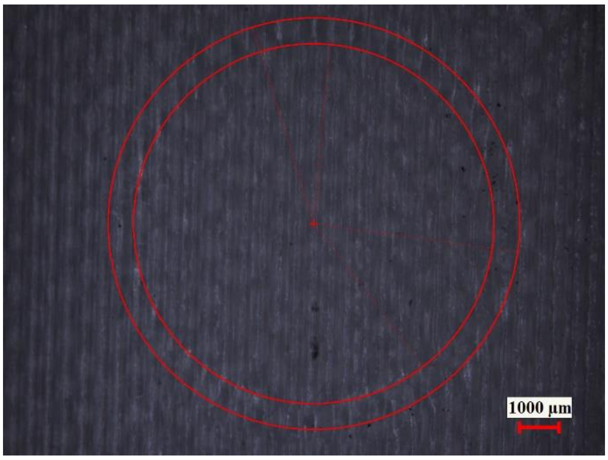


**Figure 4**. The sample wear trace

## 3. Results and Discussion

### 3.3.1. Three Point Bending Test

Three-point bending test results are given at Figure 5. Bending tests results show us that the addition of $CaCO_3$ particles in PP has a significantly negative effect on mechanical properties like bending strength of PP polymer. When Figure 5a is examined, it is seen that the strength of the composite samples is lower than pure PP and the increase of filling rate decreases the bending strength. The strength value of the 4 wt% particle reinforced composite decreased by approximately 50% compared to the pure PP. This situation could be explained by creating discontinuities in the sample due to the large size of the $CaCO_3$ particle. On the other hand, as it can be seen in Figure 1 surface of $CaCO_3$ is not very rough so the particle/matrix interface adhesion remains weak. As a result of this weakness particle reinforcement shows negative effect instead of positive effect. The decrease in strength with the increasing reinforcement ratio can be explained by agglomeration [20,21].

Although $CaCO_3$ is a rigid particle, even the modulus decreased with $CaCO_3$ particle reinforcement. Increasement of particle rate decreased the flexural modules of PP material. Finally flexural modules of the 4 wt% filled composite sample were approximately 46% worse than pure PP polymer. These results indicates that, particle matrix adhesion could not occur. In other words, it can be explained that the load on the matrix cannot be transferred to the particle, even the particles create discontinuity in the matrix and reduce the strength.

Considering the unit costs, PP polymer is 10 times more expensive than $CaCO_3$ particle. For this reason, if the decrease in mechanical strength is tolerable degree, it is possible to obtain a cheaper product with $CaCO_3$ addition.

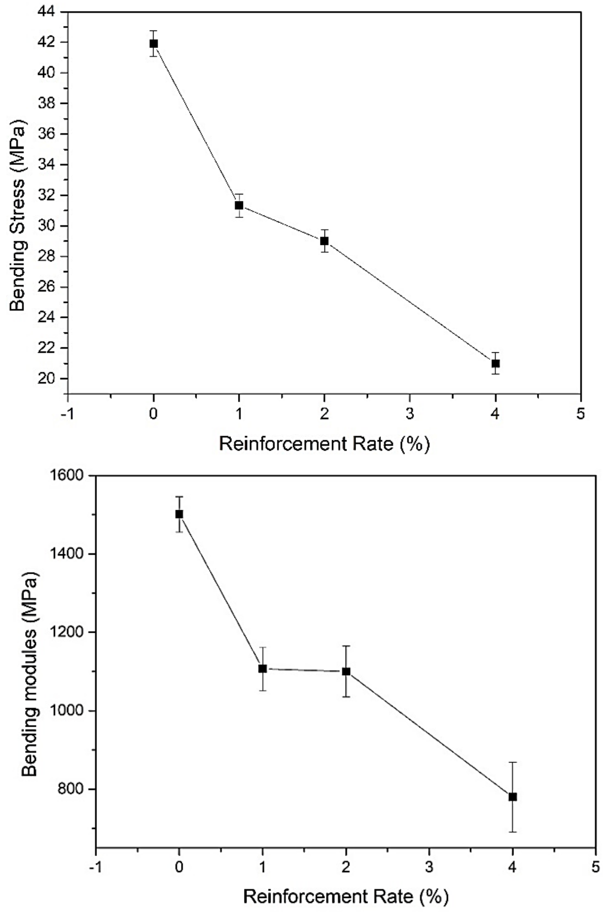


**Figure 5**. 3-point bending test results

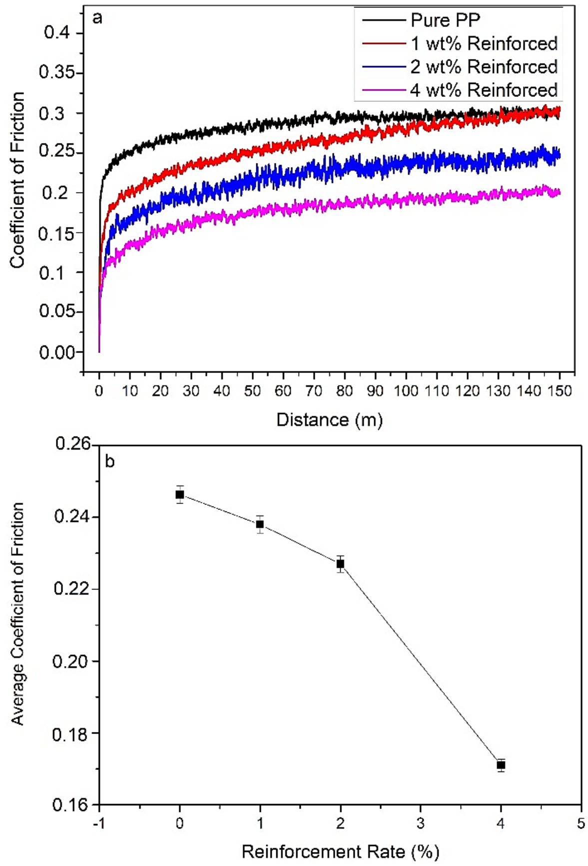


**Figure 6.** Coefficient of friction values a) during the wear test, b) average value

### 3.3.2. Wear Test

Figure 6 shows the coefficient of friction values of pure PP and composite samples. While Figure 6a shows the coefficient of friction value of samples during sliding distance, Figure 6b shows the average coefficient of friction value of samples. 4 wt% $CaCO_3$ reinforced samples showed approximately 28% lower average coefficient of friction value compared to pure PP. It is clearly seen in the two graphs that the coefficient of friction value decreased by increasing the particle reinforcement rate. This situation could be explained by the reinforcement particles acting as a lubricant between the matrix and the abrasive tip.

The wear volume results from the sliding wear test are given in Figure 7 and it is clearly seen that the wear volume decreases with particle reinforcement. In other words, the wear resistance of the samples increased with particle reinforcement. The wear resistance of PP improved about 40% by particle reinforcement. This situation could be explained by the rigid and hard structure of the $CaCO_3$ particles, which prevents the abradant ball from penetrating into the sample. Wear volume results were also supported by the coefficient of friction results [21].

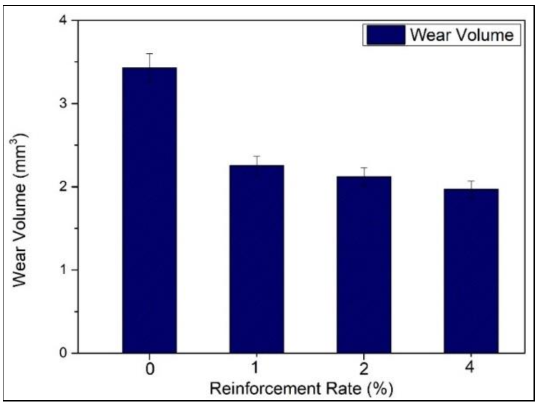


**Figure 7**. Wear volume results of worn samples

## 4. Conclusion and Suggestions

- It is demonstrated that $CaCO_3$ filled PP composite filament can be produced with this study.
- It is clearly seen that while $CaCO_3$ filling had negative effect on mechanical properties on PP, it positively affected the wear resistance. This shows that composite specimens can be used in applications that do not pose a problem in compromising mechanical strength to a certain extent but require low friction and wear resistance.
- When we compare the unit prices of polymer and reinforcement particles, PP polymer is 10 times more expensive than $CaCO_3$ particle. For this reason, the cost of the final product will be much more economical by $CaCO_3$ addition.
- The test results show that the particle-matrix interface adhesion is insufficient. For this reason, it has been seen that a compatibilizer should be used in future studies.

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**Contributions of the Authors**

All parts of manuscript were written by Assist. Prof. Alp Eren ŞAHİN

**Conflict of Interest Statement**

There is no conflict of interest between the authors.

**Statement of Research and Publication Ethics**

The study is complied with research and publication ethics

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