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PRE-TREATMENT CHARACTERISTICS FOR LCD GLASS RECYCLING: DISMANTLING, CRUSHING, AND SEPARATION

A liquid crystal display (LCD) recycling process is needed to increase its efficiency by recovering the resources in addition to metals and plastics. This study investigates the pre-treatment process for recycling LCD glass. Recycling pre-treatment includes dismantling the LCD from the waste product, crushing the glass, and separating the glass particles from the impurities. Scanning electron microscopy confirmed that the oscillation milling process is more effective in maintaining uniform powder shape and size as compared to the cut milling process. The glass particles crushed by the oscillating mill, optimized at 1500 rpm, had a uniformly distributed particle size of less than 10 μm. These small particles were separated from the organic impurities, achieving a 98% pure powder that can be used as recycled raw materials. The proposed pre-treatment process for recycling LCD glass will enhance the ability to use waste glass as a valuable resource in the manufacturing of future displays.

Keywords: Waste LCD, LCD panel, waste glass, recycling, liquid crystal display

1. Introduction

In the current low-level recycling of liquid crystal display (LCD) products, only parts such as the plastics and common metals are recovered from the entire product [1]. Considering the growing market demand and the low product lifespan, the amount of LCD waste is rapidly increasing [1-5]. However, the current recycling technology cannot meet this demand. To efficiently recycle this growing amount of LCD glass, development of a low-cost integrated recycling process is urgently needed to recover the high-quality glass and reduce material cost in the LCD industry [6-9].

The current amount of LCD glass waste in Korea alone is estimated to be 86,000 tons. This estimate includes waste from panel and glass manufacturing industries as well as consumer waste. Approximately 41% (35,000 tons) of this waste has been recycled; the remaining 59% (41,000 tons) has been entirely discarded. LCD panel glass is high-quality glass composed of SiO_2, Al_2O_3, B_2O_3, MgO, CaO, SrO, and BaO, which can be recycled into high-grade raw material. To recycle LCD glass, various impurities must be removed, such as polarizing film, color filter, liquid crystal, and other metals present in the glass. To create a usable raw material, a pulverization process is needed.

Although a number of studies have been reported for recycling of LCD in general, recycling technology in particular for LCD glass has not been developed. Although glass component content has significant shares in LCD panels which get limited attention for recycling [2]. Waste LCD glass recycling reported mostly focused on indium recovery only. Most of the indium recovery process uses thermal treatment at high temperature to remove various impurities [8,10]. High temperature process leads to potentially harmful atmospheric emissions. In the hydro-process, mechanical shredding process is often employed to separate films prior to leaching, but lacks extended information about the recovery of LCD glass [11-12].

This study developed an LCD crushing and grinding process that simultaneously pulverizes the glass while removing the impurities. And, the characteristics of pre-treatment for recycling glasses in LCD products were investigated. The recoverable resource information on waste LCD products analyzed in this study will provide various information and directions for developing efficient recycling technologies of waste LCD products in the future. And, the information will improve the recycling rate and minimize waste generation.

2. Experimental

A four-step process was used to recover the LCD panels from the waste products. First, the case of the product was removed using an electric screwdriver. This step facilitated the

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removal of the circuit board. Then, the steel frames, speaker, wires, and front case were separated. Finally, the LCD panel, sheet, steel frame, and backlight module were separated from the panel module. All of the glass material was weighed using an electronic scale to compare pre- and post-processing weights. In this study, three types of LCD glass were investigated: TV displays, tablet displays, and metal-patterned glass scraps from manufacturing processes.

A three-step process using cut mill and oscillating mill were used to complete a series of experiments for crushing and pulverizing the three types of glass. First, the LCD panel was crushed using the cut mill at 400 rpm. Next, the crushed material was injected into the oscillating mill for 30 min at varying speeds of 750, 1000, 1250, and 1500 rpm. Finally, the crushed powder was sifted for particles greater than 100 μm using a sieve shaker at 150 rpm for 30 min; this sieving separated the glass powder from the impurities.

The pulverized glass powder was analyzed by Microtrac Bluewave (Particle Size Analyzer, PSA) and Rigaku TG8121 (Thermogravimetric Analyzer) to identify the particle size and organic removal characteristics. The thermogravimetric analysis (TGA) was conducted in the temperature range of 30°C to 500°C at the rate of 10 °C/min in an air atmosphere.

3. Results and discussion

3.1. Disassembly and Weight Ratio Analysis of Waste LCD Panels

The average weight of LCDs has been steadily decreasing since 2005. The steady decrease may be caused by the replacement of some of the heavier metals in LCDs with lighter materials to reduce product weight and enhance market competitiveness. Thus, it is necessary to extend the recycling practice concentrated on conventional metals to the recycling of other valuable materials to increase the recycling efficiency of LCDs. The component parts of the LCD glass panel module, other than steel materials, were discarded, leaving an LCD panel with high-quality glass and rare metals. Furthermore, as shown in Fig. 1, the weight proportion of the LCD panel which includes glass to the whole components in the TV or tablet have been steadily increasing. The weight ratio of the LCD panel to the other components has increased up to 85%.

LCD glass is a high-quality glass that can be used as a raw material for valuable products, such as long/short glass fibers, and for low-quality products such as bottle glass. Thus, the recycling of LCD glass as a valuable resource would not only generate significant economic benefits but also increase the recycle rate of LCD products.

3.2. Crush Characteristics of LCD Glass Using the Cut Mill

Pulverization was performed by using a cut mill for crushing the LCD glass and removing impurities. A cut mill crusher is suitable for the LCD glass panels because it can break down various hard materials to a relatively uniform particle size. To analyze the crushed material from the cut mill, scanning electron microscopy (SEM) was performed. Fig. 2(a) shows the intact LCD glass panel with its cross-sectional diagram in Fig. 2(b). The glass obtained after cut milling, as shown in Fig. 2(c) and 2(d), become glass fragments; the black polarizer film can be easily removed through a simple sieving process.

Fig. 2(d) shows highlights on the glass particles, crushed to a size of 200 μm, that are considered organic matter mixture. This indicates that it is difficult to completely remove impurities from the LCD glass panel through the simple crushing process, and an additional pulverization process is required for the complete separation of the polarizer film from the glass.

3.3. Pulverization of Crushed LCD Glass Using Oscillating Mill

The oscillating mill is easy to operate and facilitates uniform pulverization in a short period of time. Fig. 3(a) and 3(b) show

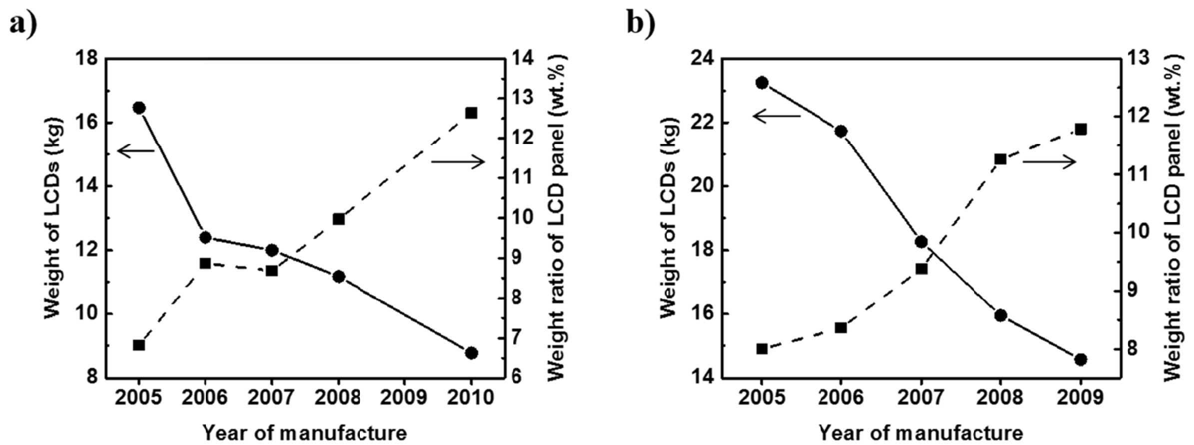

Fig. 1. Comparison between total weight and the weight of the glass panel according to manufacturing year: a) LCD products of A company b) LCD products of B company

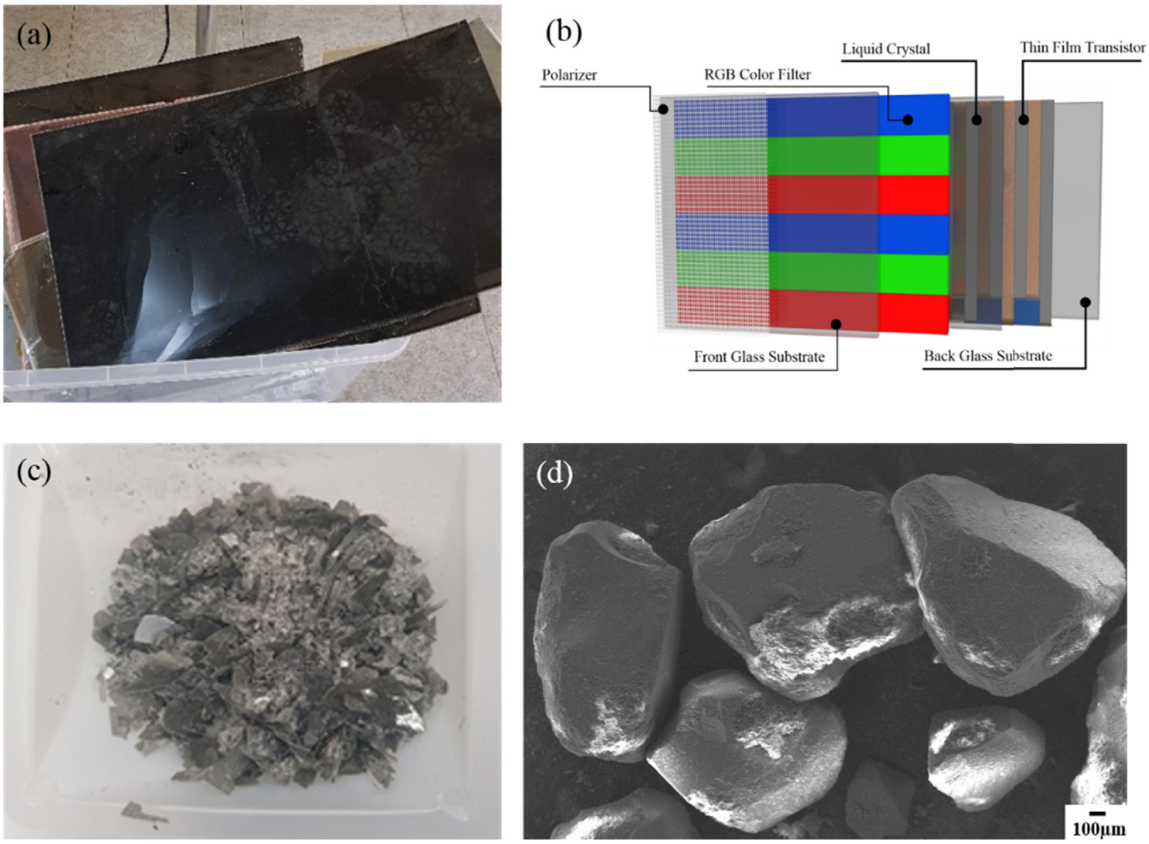

Fig. 2. Photographic images of a) the intact waste LCD glass panel, b) the layered structure of glass panel, c) waste LCD glass shredded using the cut mill, and d) SEM image of the shredded glass particles

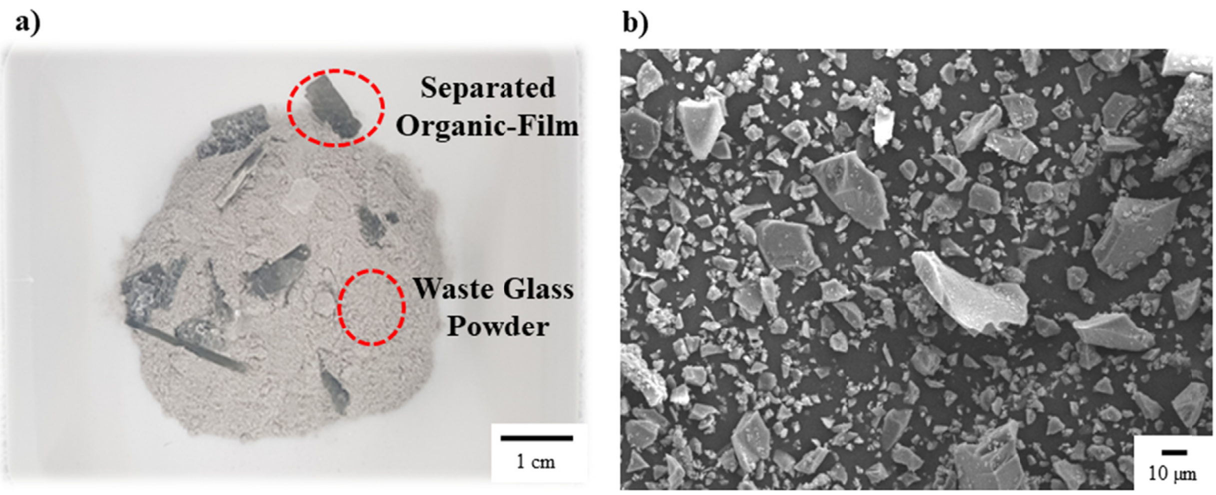

Fig. 3. a) Photographic image and b) SEM image of shredded waste LCD glass powder using the oscillating mill

a photograph and an SEM image of the crushed glass powder using the oscillating mill, respectively. As seen in Fig. 3(a), pulverization segregates the polarizer film into larger particles of 1 cm that can easily be removed by sifting. The SEM image shows glass particles of the size less than 10 μm evenly distributed and relatively uniform in shape. These results confirm that the organic matter can be separated from the glass powder effectively by the oscillation milling process.

This pulverization process of using cut mill and oscillating mill was applied to various types of display glass, which was domestically generated. To quantitatively analyze the particle size of crushed/ground powder obtained from the three types of LCD glass, particle size analysis (PSA) was performed according to the raw materials. Fig. 4 shows the PSA results of the glass powder according to milling speed and raw material.

The average particle size (D_{50}) was 3.04 μm for the glass powder generated from the tablet display. The D_{50} values for the glass powder generated from the TV display and the metal-patterned glass scraps were 1.94 μm and 2.16 μm, respectively. Therefore, the glass powder generated from tablet displays have

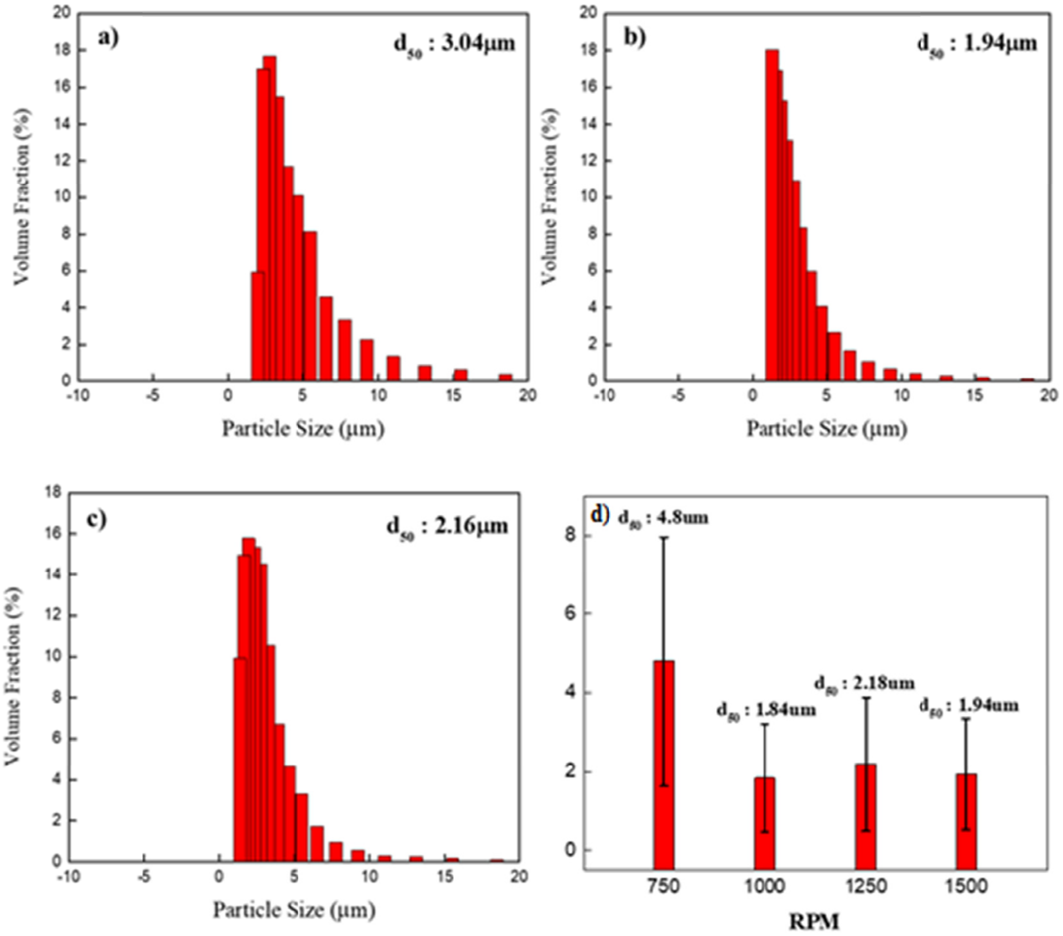

Fig. 4. PSA analysis of the crushed glass powder obtained from (a) waste tablet PC display (b) waste LCD TV display (c) waste metal patterning glass powder, (d) PSA analysis according to oscillating mill speed

a higher impurity (film) content, causing the average particle size to be larger than those of other types under the same conditions. Fig. 4(d) shows that the particle size significantly decreased as the speed increased to 1,000 rpm. At this speed, the particle size leveled off at about 2 μm, showing no more significant difference. The PSA confirmed that the LCD glass generated from all the raw materials can be pulverized to a particle size of 5 μm or less by using the oscillating mill.

Fig. 5 shows the results of the weight changes measured by TGA according to the glass types. A weight loss of 3.15% and 1.71% at 300-350°C can be observed in the tablet and TV displays, respectively. No weight loss was observed in the metal-patterned glass scraps, which did not contain organic matter. Thus, the weight loss from temperature is interpreted as the weight loss due to the combustion of the organic matter. This indicates glass powders with more than 96% organic impurity removal can be obtained by the proposed pulverization method involving a dry crushing and grinding process using cut mill and oscillating mill. Fig. 6 shows the TGA results according to speed conditions of the oscillating mill. At 750 rpm, 94.8% pure glass powder can be salvaged and at 1500 rpm, over 98% pure glass powder can be recovered because more film and adhesive particles are separated at a higher speed.

4. Conclusion

The present work studied the pre-treatment process, including dismantling of the LCD waste glass, crushing the glass, and separating the glass from the impurities, for LCD-glass recycling. The weight proportion of the LCD glass panel in the TV or tablet was found to have steadily increased up to 85% since 2005 from the dismantling investigation, indicating that the recycling of glass could generate significant economic benefits. This study proposed a recycling method that involves dry crushing and grinding processes. This recycling method can efficiently remove impurities without a separate wet process and can be applied to LCD waste from various sources. The glass powder prepared through the crushing and grinding process using cut mill and oscillating mill showed that the oscillation milling process was more effective in maintaining uniform powder size comparing to the cut milling process. The LCD glass can be pulverized to a particle size of 5 μm or less by using the oscillating mill and the glass particles crushed by the oscillating mill exhibited the maximum impurity removal efficiency of 98% at the optimized milling speed of 1,500 rpm. The pre-treatment process analyzed in this study would contribute to an integrated recycling process, thereby encouraging the recycling of LCD glass, recovering valuable raw materials, and reducing waste disposal costs.

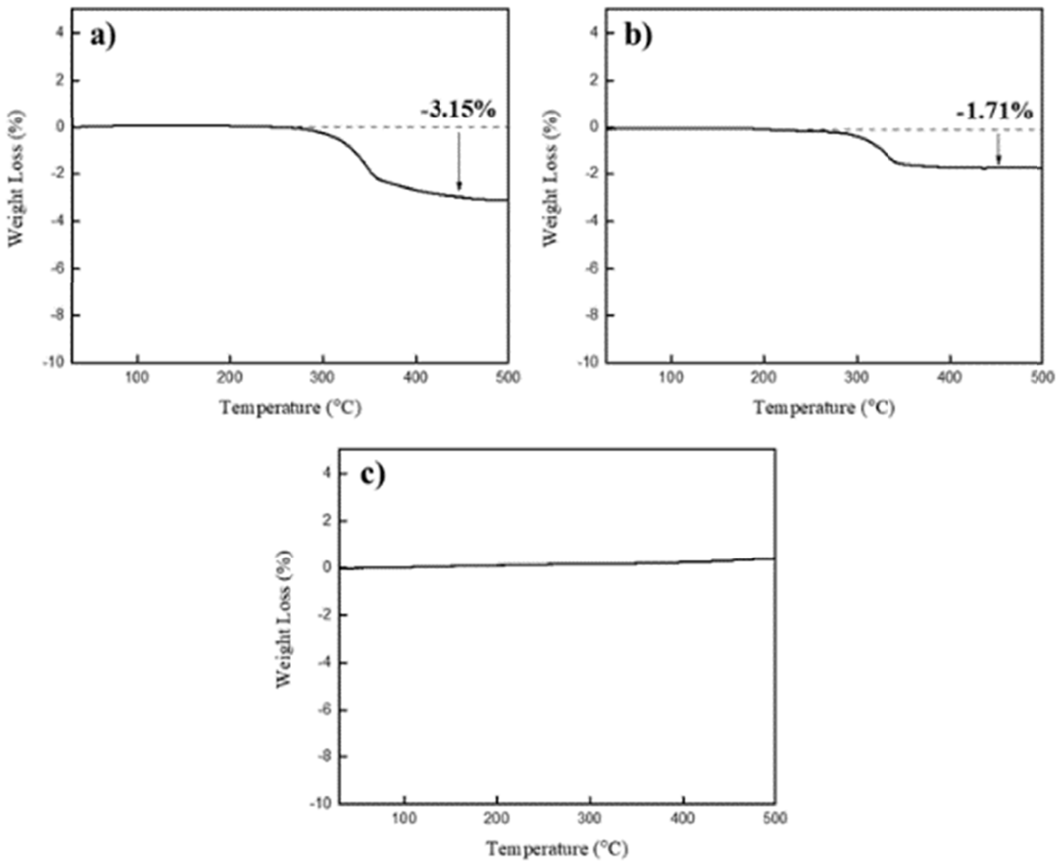

Fig. 5. TGA analysis of the crushed glass powder obtained from (a) waste tablet PC display (b) waste LCD TV display (c) waste metal patterning glass powder

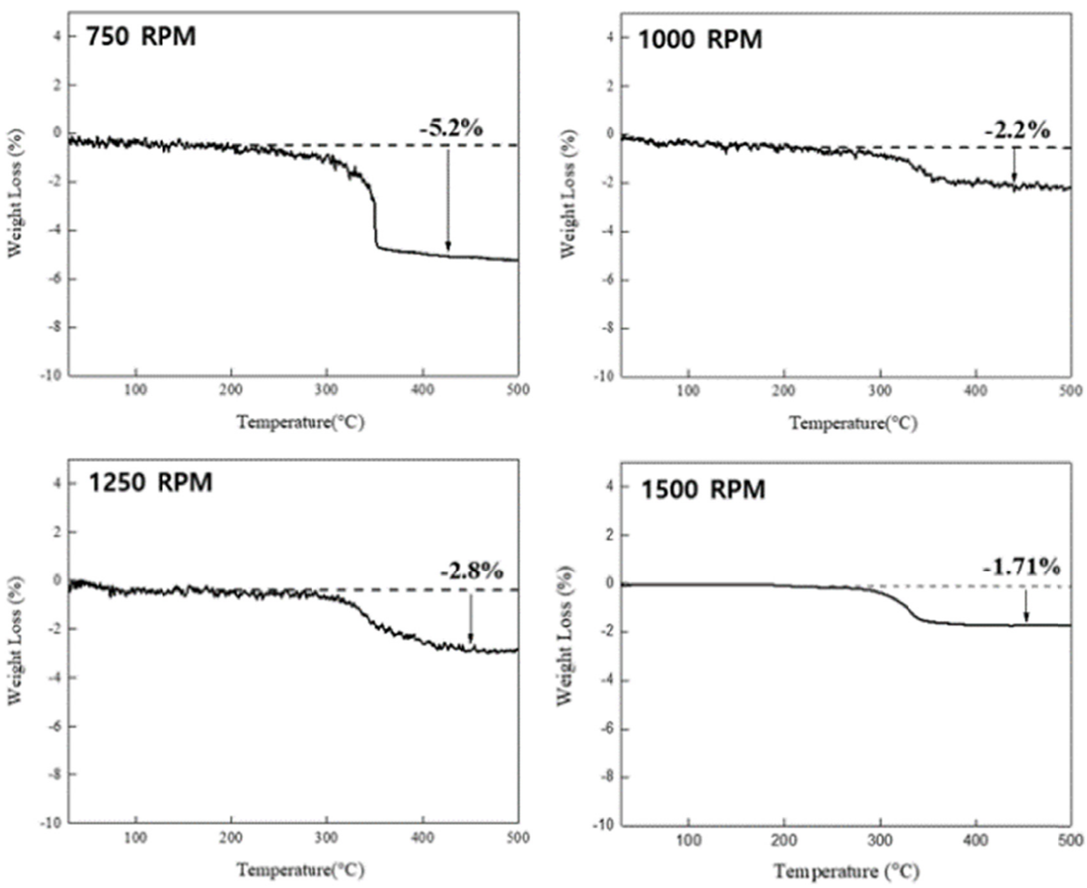

Fig. 6. TGA analysis of the prepared waste glass powder according to oscillating mill speed

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