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Recycling thin film transistor liquid crystal display (TFT-LCD) waste glass produced as glass–ceramics

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ABSTRACT

The waste electrical and electronic equipment (WEEE) directives are designed to deal with the rapidly increasing waste stream comprised of electrical and electronic equipment. Recycling electrical and electronic equipment reduces the quantity of waste going to final disposal. The demand for thin film transistor liquid crystal display (TFT-LCD) panels, commonly used in everyday electronic products, is increasing. Conventionally adopted treatments of TFT-LCD waste glass cannot meet WEEE directives. This study adopts the following operating conditions in fabricating glass–ceramics: sintering temperature of 800–950 °C; sintering time of 6 h; and, temperature increase rate of 5 °C/min. The glass–ceramic samples then underwent a series of tests, including the Vickers hardness, water absorption and porosity tests, to determine product quality. The Vickers hardness was 12.1 GPa when fired at 900 °C for 6 h, and density was 2.4 g/cm^3 and water absorption was 0%. Thus, TFT-LCD waste glass can be regarded as a good glass–ceramic material.

1. Introduction

A thin film transistor liquid crystal display (TFT-LCD) is an LCD that uses TFT technology to upgrade image quality (e.g. addressability and contrast). Such TFT-LCDs are used in televisions, as computer monitors, in mobile phones and computers, personal digital assistants, navigation systems, and projectors. Indium tin oxide (ITO) or tin-doped indium oxide is a mixture of indium (III) oxide (In_2O_3) and tin (IV) oxide (SnO_2), typically at 90% In_2O_3 and 10% SnO_2 by weight. Notably, ITO is used to make transparent conductive coatings. Thin film layers can be deposited by electron-beam evaporation or sputtering. Typical applications of ITO-coated substrates are touch panel contacts, electrodes for LCDs and electrochromic displays, energy-conserving architectural windows, defogging aircraft and automobile windows, heat-reflecting coatings to increase light bulb efficiency, gas sensors, antistatic window coatings, and wear-resistant layers on glass.

The amount of waste glass dumped into landfills was approximately 0.52 million tons in Taiwan in 2009, whereas the amount of TFT-LCD waste has reached 6000 tons [1]. The Waste Electrical and Electronic Equipment (WEEE) Directive, implemented by European Community, attempts to reduce the amount of WEEE produced and encourage reuse, recycling and recovery, thereby providing incentive to design electrical and electronic equipment in an environmentally efficient manner that considers waste management. The WEEE Directive also aims to improve the environmental performance of businesses manufacturing, supplying, using, recycling and recovering electrical and electronic equipment. Nevertheless, sintering technique can produce monolithic glass, which, when subjected to controlled thermal treatments, can be transformed into glass–ceramics, particularly wollastonite ($CaO\cdot SiO_2$), diopside ($CaO\cdot MgO\cdot 2SiO_2$), anorthite ($CaO\cdot Al_2O_3\cdot 2SiO_2$) and iron oxides ($Fe_2O_3$ and Fe_3O_4) [2–5], for use as coating materials with excellent chemical and mechanical properties for building or thermo-mechanical applications [6,7]. Notably, TFT-LCD waste glass is potentially valuable source of major oxides, such as CaO and SiO_2, which are common in glass. [8]

Generally, the crystallization involved in the vitrification treatment could take place in different modes. (1) Crystallization occurs during very slow cooling; various minerals can be formed when the

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Table 1
Chemical composition and total heavy metal of TFT-LCD waste glass.

Composition	TFT-LCD waste glass
SiO_2 (%)	72.84
Na_2O (%)	0.3
CaO (%)	20.06
Cu (mg/kg)	11
Zn (mg/kg)	77
Pb (mg/kg)	5
Cr (mg/kg)	11
Cd (mg/kg)	N. D.[a]

[a] N.D.: Not detection.

melt is gradually cooled. The crystallization of igneous rocks, such as granite, belongs to this type. (2) Crystallization occurs upon supercooling. In order to avoid forming high temperature crystalline phases, such as magnetite or olivine, the melt is rapidly cooled to certain temperatures to obtain individual mineral phases. (3) Crystallization takes place during vitrification heat treatment. To form a better glass–ceramic the crystalline behavior of these minerals needs to be encouraged by higher heat treatment temperatures. Both the porosity and water absorption rate properties are improved with increasing heat treatment temperatures [9]. The sintering process consists of a thermal treatment for coherently bonding particles, in order to enhance the strength and the other engineering properties of the compacted particles. It is an effective alternative treatment for the resource recycling of waste. The thermal heating destroys organic residue and stabilizes inorganic material and metals by incorporating oxides from the elemental constituents into a ceramic-like material [10–13]. This study employs the following operating conditions to fabricate glass–ceramics: sintering temperature of 800–950 °C; sintering time of 6 h; and, temperature increase rate of 5 °C/min. The glass–ceramic samples were then subjected to a series of tests to determine their quality, including the Vickers hardness, water absorption and porosity tests. The crystalline phases of all heat-treated samples and the untreated ground mixture were identified by X-ray diffraction (XRD) analysis and Fourier transformation infrared spectroscopy (FTIR). In this study, non-isothermal investigations of crystallization kinetics were conducted using Differential Thermal Analyzer (DTA) measurements. The activation energy of crystal growth was determined and the optimal heat treatment was defined.

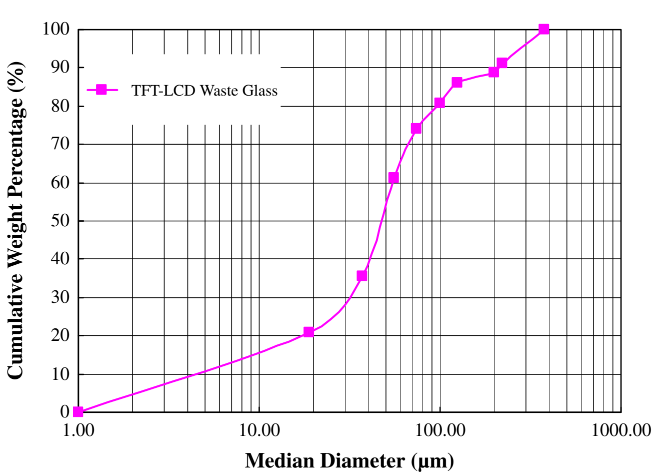

Fig. 1. Particle size distribution of the TFT-LCD waste glass.

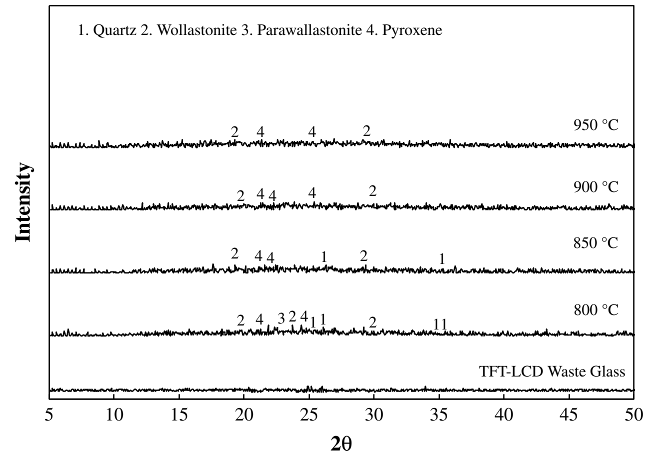

Fig. 2. The XRD patterns of TFT-LCD waste glass and glass–ceramic samples.

2. Materials and methods

2.1. Materials

The TFT-LCD waste glass was obtained from a TFT-LCD manufacturing plant in Taiwan. The TFT-LCD waste glass was crushed to a uniform particle size, ground until it could pass through a 16-mesh sieve and then dried. The chemical composition of raw materials was analyzed by X-ray fluorescence (XRF). Table 1 shows the chemical composition and total heavy metal of TFT-LCD results.

2.2. Experimental procedures

To investigate the feasibility of reusing TFT-LCD waste glass to make glass–ceramic tiles, the TFT-LCD waste glass was homogenized in a blender and then molded under a pressure of 200 kg/cm^2 to form 20 $mm^{(\Phi)} \times 4.8\ mm^{(H)}$ cylindrical specimens. The results obtained from the laboratory tests can be applied to the commercial size tile since it was constructed by the same component and process. Therefore, the scale up of the glass–ceramic sample should be acceptable in this study. The molded specimens were air-dried at room temperature for 24 h, oven-dried at 105 °C (ASTM D 2216) for another 24 h to remove water, and then heated to the desired temperature (800, 850, 900 and 950 °C), at a rate of 5 °C/min. This temperature was maintained for 6 h to bake samples; the samples were then cooled to room temperature. At least three samples were tested in each experiment.

2.3. Analytical methods

The glass–ceramic tile samples then underwent a series of tests, including firing shrinkage, water absorption, bulk density and hardness (CNS 3299) tests, to determine their quality. Hardness and fracture toughness were obtained by the Vickers indentation

Table 2
TCLP concentrations in TFT-LCD waste glass.

	Pb (mg/L)	Cd (mg/L)	Cr (mg/L)	Cu (mg/L)	Zn (mg/L)
Waste Glass	ND[a]	ND	ND	ND	0.09
Regulatory limits	5	1	5	15	–

[a] N.D.: Not detection.