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Development of recycled PET fiber and its application as concrete-reinforcing fiber

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Abstract

We describe a method that can be used to produce concrete-reinforcing PET fiber from used PET bottles. Using this method, the concrete and PET fibers are easily mixed at a fiber contents as high as 3%. The primary characteristic of the PET fiber is that it is easy to handle. The issue of concern in the development of PET fiber is its alkali resistance; however, we encountered no problems when using the fiber in normal concrete. The wetting tension of PET was found to be lower than that of PVA but higher than that of PP. No toxic gas was generated during a combustion test of the PET fiber. We describe two example applications: a gateway support at Hishikari Mine, Japan, and the pavement of bush roads.

Keywords: Fiber-reinforced concrete; Recycled PET; PET fiber; Alkali resistance; Mixing; Strength

1. Introduction

Steel fiber [1], glass fiber [2], and plastic fiber [3] are used as concrete-reinforcing material for tunnels and underground structures [4,5]. The application of concrete-reinforcing fiber has been gradually expanded by making greater use of the individual characteristics of the fibers. Polypropylene (PP), polyethylene (PE), nylon, aramid, and polyesters are commonly used as synthetic fibers in this regard.

Polyethylene terephthalate (PET) analyzed in the present study belongs to the polyester group. PET has been used increasingly in recent years, including use as PET bottles. The following methods have been proposed to reuse PET bottles: conversion to unsaturated polyester and mixed to form polymer concrete [6], and mixing of fragments in concrete to be used as lightweight waste aggregate [7]. However, as the strength of conventional PET fiber is low and its alkali resistance is questionable [3], it has rarely been used as a concrete-reinforcing fiber.

In this study, we started with the development of a production method for concrete-reinforcing PET fiber. Pellets produced from PET bottles were melted and drawn to produce monofilaments; during this process, caution was taken to ensure that sufficient strength would be installed in the monofilaments. Subsequently, indents were marked on the monofilaments and they were cut to produce PET fiber. Temperature control of the monofilaments was found to be crucial for accurate indentation. After a period of trial and error, the appropriate temperature range was found to be 68–73 °C, which is close to the glass transition point of the PET fiber.

At this point, we tested the wetting tension, alkali resistance, and combustion gases of the produced PET fiber. In all tests, we obtained desirable results for the concrete-reinforcing fiber. Following this, the mixability of the PET fiber was examined by hand mixing; the PET fiber was found to mix very easily with concrete. The machine-mixing ability of the PET fiber with concrete was also found to be good. Next, we conducted a bending test of the

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PET-fiber-reinforced concrete; the measured JCI (Japan Concrete Institute) toughness was found to have increased greatly relative to that of the same material without reinforcement. A pull-out resistance test of the PET fiber was also conducted, and the adhesion of the fiber per surface area was found to compare favorably with that of PP fiber. Following the above-mentioned basic tests of the PET fiber, the PET-fiber-reinforced concrete was used to support a mine gateway and pave bush roads. In all cases, the PET fiber was applied without any problems.

2. Preparation of PET fiber

To minimize costs and contribute to material recycling, we used pellets recycled from PET bottles as the raw material for the production of PET fiber. The properties of plastic fiber vary widely depending upon the production method. In the normal process, pellets are melted, extruded from a nozzle, and drawn into fiber while warm. When melted plastic is drawn in this way, the polymer chains align along the longitudinal direction of the fiber. As a result, the strength of the fiber is increased by more than an order of magnitude.

After various considerations, we decided to produce monofilaments, which are used as the raw material for the PET fiber, using an extruder, as shown in Fig. 1. Pellets were placed in the extruder and melted; 20–100 fibers were then extruded from the nozzle at the tip of the extruder. The nozzle was disk-shaped and had numerous small holes. Through these small holes, fibers with a fineness of 60,000 dtex (decitex: grams per 10,000 meter length) were extruded. Temperature control during the extrusion process is generally very difficult. After some trial and error, the temperature inside the extruder was set at 250–280 °C and the temperature of the nozzle was set at 260–280 °C. The extruded fiber was pulled to the godet roll and hot-drawn to a fineness of 25,000 dtex. The fiber was further drawn in a water bath filled with cold water, and a fineness of 5000 dtex (diameter of ~ 0.7 mm) was achieved when it reached the snub roll.

The resulting monofilament was a smooth fiber with a circular cross-section. Judging from our experience with steel fiber and based on the results of simple preliminary tests, we inferred that the fiber would be easily pulled out from the concrete if there were no indents on the fiber. Therefore, we developed a process to produce indents and incorporated this into a fiber-cutting apparatus, as shown in Fig. 2. The rolled monofilament is on the bobbin on the right side of Fig. 2, and it is pulled with the pinch roll #1 and gradually reeled out. We marked indents on

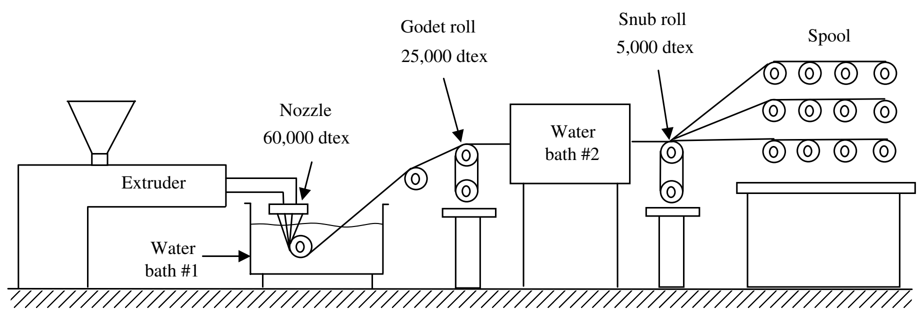

Fig. 1. Extrusion apparatus for monofilaments.

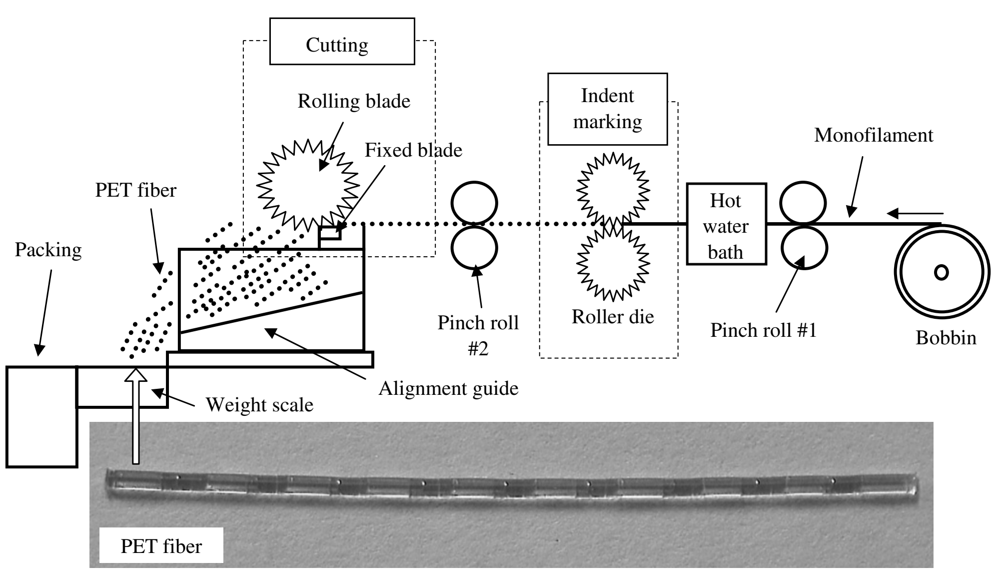

Fig. 2. Apparatus for the indent marking and cutting of PET fiber.