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Technical Report

Preparation and properties of novel building materials at low temperature

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A B S T R A C T

With the rapid development of science and technology, civil engineering in the cryogenic environment has become popular. It is reported that Pykrete (a mixture made of approximately 14 wt% of sawdust and 86 wt% of water) is stronger after cryogenic treatment. We utilized newspaper instead of sawdust and added Sodium Carboxyl Methyl Cellulose-Gelatin Polyelectrolyte Complex (SGPC) into water to make Ultimate Pykrete in order to improve mechanical strength. Results indicate that Ultimate Pykrete has several desirable properties including high strength, low weight and short curing time, therefore can potentially be utilized as a building material for civil engineering in the cryogenic environment with the demand of sustainable development.

1. Introduction

Smog has become a hot issue in all over the world recent days, and the government is taking actions to fight against pollution [1]. Concrete is a commonly used building material. However, the production process of concrete always causes various kinds of pollution, such as water pollution and air pollution. Moreover, it is reported that after 10 freeze–thaw cycles from −40 °C to 0 °C, compressive strength and flexural strength of concrete decrease dramatically, by approximately 11.8% and 41.2% [2–5], respectively. Therefore, novel building materials are in great demand in the cryogenic environment.

Pykrete was used as a kind of composite materials to build a frozen fleet in the *Habbakuk* Project of World War II. It contains approximately 14 wt% of sawdust and 86 wt% of water. Perutz [6] and Gold [7] reported its two major characteristics: high strength (potentially bulletproof) and low melting rate due to low thermal conductivity. In our study, we first utilized newspaper to improve fiber length. Then we added Sodium Carboxyl Methyl Cellulose-Gelatin Polyelectrolyte Complex (SGPC) to improve binding force between fiber. Finally, we managed to find the optimum ratio ranges of SGPC, and made Ultimate Pykrete. It can potentially be utilized as a building material for civil engineering in the cryogenic environment (such as the North Pole or South Pole), and meet the sustainable requirements.

2. Materials and methods

2.1. Materials

Analytical Reagents were used including Polyacrylamide (PAM), Tianjin Fu Cheng Chemical Reagent Factory; Sodium Carboxyl Methyl Cellulose (SCMC), Tianjin Zhi Yuan Chemical Reagent Factory; Gelatin, Tianjin Bo Di Chemical Company; Agar, Shanghai National Medicine Group. Equipment included universal testing machine (UTM), scanning electron microscope (SEM, Hitachi TM-3000), vacuum freeze drier and freezer.

2.2. Specimens preparation

The calculated amount of sawdust (or newspaper) and water (mixed with a certain amount of gel if necessary) was mixed in standard molds in order to prepare specimens, shown in Fig. 1(a). After sawdust (or newspaper) completely soaked in water and any bubbles purged, molds were placed in a freezer at appropriate temperature (−40 °C) for 48 h.

2.3. Test methods

2.3.1. Method for testing compressive strength

Compressive strength was tested using specimens with size of 150 mm × 150 mm × 150 mm, according to national standard of P. R. C.: GB/T 50107-2010 [8] and GB/T 50081-2002 [9].

Compressive strength is calculated as

$$f_{cu} = \frac{P}{A} \tag{1}$$

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where f_{cu} denotes compressive strength (MPa); P is compressive load (N); A is the contact area (mm^2).

2.3.2. Method for testing flexural strength

Three-point bending tests were conducted to test flexural strength using specimens with size of 150 mm × 150 mm × 550 mm, based on ASTM: C78 and ASTM: C1609, shown in Fig. 1(b).

Flexural strength is calculated as

$$f_f = \frac{Fl}{bh^2} \tag{2}$$

where f_f denotes flexural strength (MPa); F is flexural load (N); l is span length (450 mm), b is specimen width (150 mm), h is specimen height (150 mm).

2.3.3. Method for calculating the ratio of compressive strength to flexural strength

The ratio of compressive strength to flexural strength is calculated as

$$\sigma_{cu/f} = \frac{f_{cu}}{f_f} \tag{3}$$

where $\sigma_{cu/f}$ denotes the ratio of compressive strength to flexural strength.

2.3.4. Method for observing microstructure

Specimens after a 48 h curing period were crushed into sliced specimens (5 mm × 5 mm × 2 mm). They were pre-cooled for 30 min, frozen dry for 3 h in the vacuum freeze drier and taken images by SEM.

3. Results and discussion

3.1. Testing mechanical strength of Pykrete

Pykrete specimens were prepared according to specified ratios of sawdust and water [6,7].

Pykrete has shown high strength and good toughness (Table 1). Compressive strength (f_{cu}) is 12.25 MPa, 40.8% of concrete (30.00 MPa), while flexural strength (f_f) is 4.86 MPa, 108% of concrete (4.50 MPa). We infer that longer fiber can greatly enhance mechanical strength. Therefore, improving fiber length is in great demand to improve mechanical strength of Pykrete.

Table 1
Mechanical strength of Pykrete.

Specimens	f_{cu}/MPa	f_f/MPa	$\sigma_{cu/f}$
P_1	11.57	4.37	2.65
P_2	12.48	5.11	2.44
P_3	12.57	5.00	2.51
P_4	11.96	4.69	2.55
P_5	12.68	5.12	2.48
$\bar{X}$	12.25	4.86	2.53
S_X	0.42	0.29	0.07

Note: P_1–P_5 are parallel Pykrete specimens. $\bar{X}$ is the average mechanical strength of specimens and S_X is mechanical strength standard deviation of measurements. f_{cu} is compressive strength of Pykrete specimens. f_f is flexural strength of Pykrete specimens. $\sigma_{cu/f}$ is the ratio of compressive strength to flexural strength of Pykrete specimens.

Table 2
Mechanical strength of New Pykrete.

Specimens	f_{cu}/MPa	f_f/MPa	$\sigma_{cu/f}$
N_1	21.73	8.21	2.65
N_2	21.43	7.89	2.72
N_3	21.35	7.35	2.90
N_4	21.52	8.01	2.69
N_5	21.18	8.73	2.42
$\bar{X}$	21.44	8.04	2.68
S_X	0.18	0.45	0.15

Note: N_1~N_5 are parallel New Pykrete specimens. $\bar{X}$ is the average mechanical strength of specimens and S_X is mechanical strength standard deviation of measurements. f_{cu} is compressive strength of New Pykrete specimens. f_f is flexural strength of New Pykrete specimens. $\sigma_{cu/f}$ is the ratio of compressive strength to flexural strength of New Pykrete specimens.

3.2. Improving fiber to make New Pykrete

Mechanical strength of composite materials is usually determined by fiber length. For example, concrete made from modified fiber could have improved compressive strength and flexural strength [10,11]. Instead of sawdust, longer fiber from newspaper was used to make New Pykrete in this study. Mechanical strength of New Pykrete is shown in Table 2.

Compressive strength of New Pykrete is 21.44 MPa (71% of concrete) while flexural strength is 8.04 MPa (179% of concrete), shown in Fig. 2. Furthermore, it will not be damaged easily when frozen. Therefore, New Pykrete is indeed a more advanced building material than Pykrete in the cryogenic environment.

3.3. Adding gel to enhance binding force

Hydroxyl groups in fiber are mainly bonded by hydrogen bonds. Gel is already widely used in the pulp and paper industry to

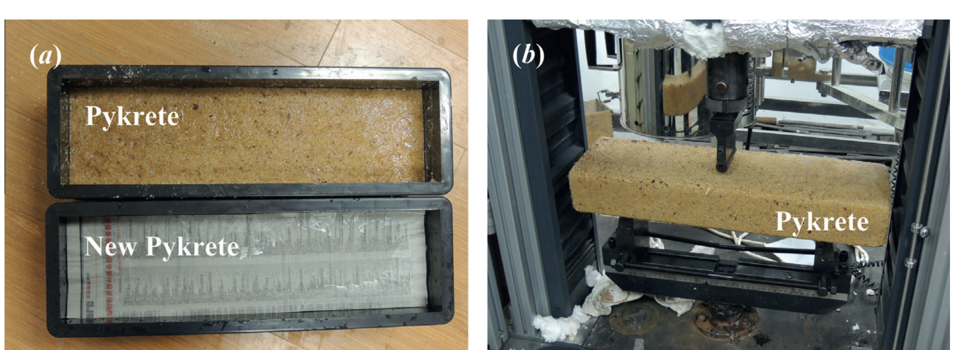

Fig. 1. (a) Pykrete and New Pykrete specimens and (b) flexural strength test.