UTILIZATION OF WASTE BAKELITE AS A FIBER REINFORCE TO IMPROVE MECHANICAL PROPERTIES OF CONCRETE

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Abstract

Waste Bakelite is mainly from automotive production, it can create waste management problems due to its toxic substances. The consensus of previous research works in waste Bakelite as aggregate in concrete mixture and mortar still has problems such as low strength and high toxics of concrete products. Selected shapes of waste Bakelite are similar to a fiber which could be used to reinforce concrete. In this research, waste Bakelite was selected into a suitable shape and was mixed with a proportion of 0%, 3%, 5%, and 7% by volume of concrete. The slump of fresh concrete, compressive strength, and flexural strength were tested. The results discovered that the addition of 3% to 7% waste Bakelite bar as a fiber had no negative significant impact on the workability of fresh concrete. In addition, the adding bar shape of waste Bakelite 5% by volume into concrete showed a positive effect on the mechanical tensile strength and flexural strength of concrete while the product shows almost non-toxics discharge from colorimetric observation.

Keywords: **Waste plastic, Bakelite, Fiber-Reinforced Concrete, Flexural Behavior, Toxic**

Introduction

Bakelite, which is thermosetting phenol-formaldehyde resin, has been producing as auto parts and the consumer goods. In Thailand, original material of this waste is categorized as a thermosetting plastic while the waste is mainly a by-product from car manufacturing (car parts). The waste from thermosetting plastic is not suitable for normally recycle. Due to increasing of Bakelite consumption results in Bakelite waste, which is a hazardous solid waste that has made waste management problem (Thachampuram and Paul, 2018). Utilizations of waste Bakelite as aggregate in cement mortar and concrete were studied (Usahanunth, 2016; Usahanunth and Tuprakay, 2017; Thachampuram and Paul, 2018; Usahanunth *et al*., 2018). Then, recycling the left-over Bakelite as components in concrete and mortar, might be a significant.

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Usahanunth and Tuprakay (2017) reduced Bakelite into smaller size particles by using a Hammer mill machine and sieves. Small size of milled waste Bakelite was added into cement mortar as a replacement material of natural fine aggregate at different proportions between 0% and 100%, and compressive strength of the mortar samples was tested. Although, this work reveals that partial replacement by milled waste Bakelite in mortar result in compressive strength (age of 7 days and 28 days) of the mortars were lower than conventional mortar. They found that the content of milled waste Bakelite as fine aggregate in concrete and brick plastering mortar were limited to 11.03% and 23.80% by volume, respectively. Dramatic decrease of compressive strength occurs as increasing the milled waste content whereas the strength of Bakelite is approximately 200 MPa (HEXION, 2018; Sumitomo, 2018) which is extremely high when compared with the control mortar strength (7.6 MPa). It means that milling of the waste to form fine aggregate gives a negative result in the strength of post-milling waste Bakelite. Moreover, heavy metals (i.e., Ni, As, Cd, Pb, Hg, and Cr) were detected in the curing water. As well, the measured concentration of toxic substances are over the limit of the standard effluent water restricted by the department of industrial works, ministry of industry (2017).

Usahanunth *et al*. (2018) deals with the chemical, mechanical and physical properties of Bakelite. Waste Bakelite coarse aggregates (WBAC) was mixed with a proportion of 20%, 40%, 60%, 80%, and 100% by volume to replace the natural coarse aggregates while the waste Bakelite fine aggregates (WBFA) was replaced as fine aggregate at rate of 10%, 20%, 30%, and 40% by volume. The strength reduction of waste Bakelite concrete showed as increasing of waste Bakelite coarse aggregate content. The reducing in the strength probably due to weak bonding between the inter-transition zone of Bakelite aggregate and cement matrix. In other words, natural aggregate has a rougher surface and better bonding than milled Bakelite. Twenty percentage of replacement by volume of WBAC (without WBFC) was recommended by this paper. This work shows that concrete with 40% WBCA has 83% (25.8 MPa / 31.1 MPa) 28-day compressive strength of non-Bakelite concrete (control mix) while concrete with 40% Waste Bakelite fine aggregates has zero 28-day compressive strength. In other words, the reduction rate of compressive strength depends on replacing fine aggregate tremendously more than that of coarse aggregate. In addition, the slow hardening of WBAC when natural fine aggregate was replaced by waste Bakelite fine aggregates was found as longer than 24 hours. The contamination of phenol and formaldehyde of almost all test mixtures exceeded the limit of the standard effluent water that issued by the department of industrial works, ministry of industry (2017). Pholkoed (2020) reported the carbon footprint of the Bakelite plastic-mixed concrete production process was 558.34 kg.CO_2/m^3 (The same proportion of Usahanunth *et al*., 2018), which had a higher carbon footprint than the general concrete production process. Murali and Sambath (2020) also shows that the strength of concrete and solid block at the age of 28 days, in which coarse aggregate was partially replaced with Bakelite (0% to 30%) are gradually decreased by increasing the percentage of replacement of transform Bakelite (coarse aggregate). These researches confirm that transform Bakelite to be coarse aggregate or fine aggregate gives an adverse effect in terms of strengths of concrete.

Thachampuram and Paul (2018) researched with the main objective is to reduce the waste plastic and also to improve the environment. The research partially replaces Bakelite as fine aggregates from 10% to 25% by weight, into concrete. The results show that 15% replacement of Bakelite was the optimum amount results in dense concrete and the highest compressive cube strength of Bakelite concrete. Moreover, flexural strength, split tensile strength, shear strength, and modulus of elasticity are also good agreement with compressive cube strength which is lower than the control mixture (Non-Bakelite). However, Dharanidharan *et al.* (2015) studied the properties of shredded waste plastic (Bakelite) in concrete by partial replacement as an aggregates. The results show that using of shredded waste plastic increases the stiffness of the concrete while reduces the ductility of the concrete. They concluded that the shredded waste plastic up to 8% may be used for the replacement of aggregates in concrete without adverse effect on compressive strength and flexural strength.

Concrete is a brittle material which has low tensile strength, and it is easy to crack due to tensile stress. In order to improve its compressive and flexural strength properties, adding of small and uniformly dispersed fibers into concrete could work as a crack arrester. This type of concrete with fibers is known as fiber reinforced concrete. Gadge and Vidhale (2013) found that the best amount for the addition of steel fiber is 1.5%. The percentage of increase in 28 days-flexural strength for M20, M30, and M40-grade with steel fiber (1.5%) are 20.37%, 25.37%, and 56.39% respectively. They concluded that higher fiber content improved the compressive strength, flexural strength, abrasion resistance, and crack-control effect. Therefore, utilization of waste materials as a fiber-reinforce in concrete should be feasibility studied.

Although, many consensuses are the strength reduction which is consistently reported in waste Bakelite concrete, the main objective of this study is the utilization of waste Bakelite from industrial manufacturing as fiber reinforcement in concrete to improve the flexural strength. This work initiated to explore the advantage from high strength of waste Bakelite while sinuously discover the measure to avoid the toxic substances released from waste Bakelite concrete.

Materials and Methods

The selection of waste Bakelite in this experiment

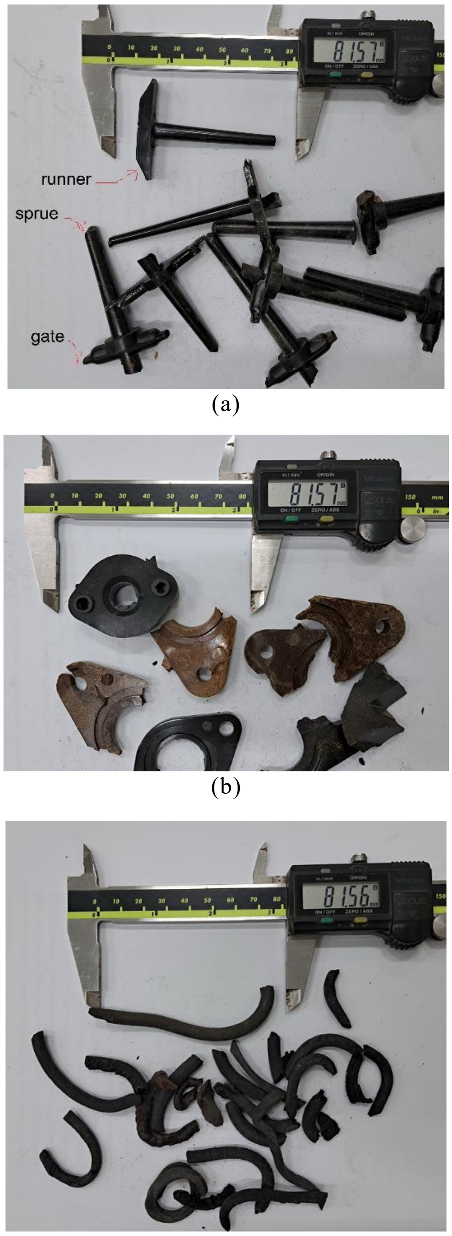
Waste Bakelite was visually investigated. Then, the waste Bakelite forms were separated into three characters as shown in Figure 1.

In Figure 1 (a) bar and T shapes are waste Bakelite from injection molded components which are sprue, runners and gate, (b) lumped shape is from fault products or other imperfection components while (c) soft rolled shape is non-finish in injection process of manufacturing.

Since, this work focuses on improvement the flexural strength of concrete with waste Bakelite as a fiber. Therefore, this work used bar and T shapes of waste Bakelite which were not ground by any milling machines. The bar and T-shaped waste Bakelite is the connection of a sprue with runners. Sprues are approximately 6 to 7 cm long with a diameter of about 6 mm, tapering at a 5-degree angle. The runner has a diameter of around 6 mm. The selected Bakelite which is similar to a fiber for concrete, has approximately 7.5 cm. long and bulk specific gravity is around 1,505 kg/m^3. In addition, dry bulk specific gravity of lumped shape and soft rolled shape are 1,412 kg/m^3 and 1,244 kg/m^3, respectively.

Materials

Portland cement Type I (Elephant brand, complying with ASTM C150-99, coarse aggregate from lime stone and natural river sand were used in this research. All aggregates were prepared in saturated surface dry (SSD) condition and it was sieved to obtain the standard requirement gradation according to ASTM C33-99. The maximum coarse aggregate sizes is 25 mm. The bulk specific gravity (SSD) is 2.67 whereas the fineness modulus of fine aggregate is 2.8, which is in the limit according to ASTM C 33-99.



(a)

(b)

(c)

Figure 1. Waste Bakelite (a) bar and T shapes, (b) lumped shape, (c) soft rolled shape

Testing program

The study aims to investigate the strength-related properties of concrete. The same proportion of Usahanunth et al. (2018) was selected to be the control mixture. The mix proportions are shown in Table 1. The waste Bakelite (WB) was added into the concrete mix as a fiber at the rate of 0%, 3%, 5%, and 7% by volume of concrete. Concrete was mixed using a drum-type mixer. Before molding, slump of fresh concrete was measured (ASTM C143-15). Then, the standard cube (15x15x15cm), split tensile strength specimen (15x30 cm cylinder) and flexural specimen (10x10x40cm) of concrete samples were prepared in oiled metal molds (compacted with a steel rod, placed in 3 layers). After 24 hours, the specimens were demoded and stored in curing water until the date of testing. At the age of 7 and 28 days, three experiments were conducted: 1) compressive strength determination according to BS 1881-part-116-83, 2) splitting tensile test of cylindrical concrete according to ASTM C496-17 and 3) modulus of rupture according to ASTM C78-18, standard test method for flexural strength of concrete. The compressive strength, the tensile strength, and the flexural strength were calculated from the average value of three specimens.

Table 1. Waste Bakelite (a) bar and T shapes, (b) lumped shape, (c) soft rolled shape

Mix	Waste Bakelite (kg/m^3)	Remarks
Control	0	0 % of WB by V
WB3V	42	3 % of WB by V
WB5V	70	5 % of WB by V
WB7V	98	7 % of WB by V

*All mixtures were controlled amount of cement, gravel, sand, and water at 380, 1060, 740 and 200 kg/m^3, respectively.

Results and Discussion

Five parameters - namely slump, compressive strength, splitting tensile strength, flexural strength and colorimetric of the specimens - were experimentally investigated. The results for each parameter are presented and discussed as follows:

Slump Test (Workability)

In this study, the proportion of Usahanunth *et al.* (2018) was selected to be the control mixture which has medium workability (slump value 6-12 cm) while the control mixture in this experiment shows 17 cm. of slump. It should be noted that the quality of aggregate in control mixture of this research might be slightly different from Usahanunth *et al.* (2018). The effect of the volume of waste Bakelite as a fiber on the slump of fresh concrete is shown in Figure 2. The slump chart in Figure 2 shows that no significant effect of waste Bakelite adding on the workability of concrete was observed. This shows that addition of waste Bakelite 3% to 7% into concrete give a tiny negative effect on the workability which was measured by slump test.

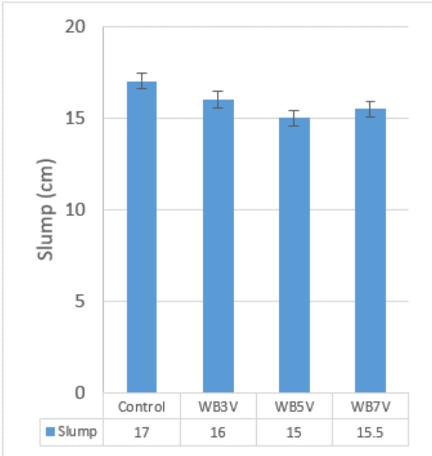


Figure 2. Slump of Waste Bakelite Concretes

Compressive Strength

In this study, the proportion of Usahanunth *et al.* (2018) was selected to be the control mixture which has 23.5 MPa and 31.1 MPa compressive strength at the age of 7 days and 28 days, respectively. Figure 3 demonstrates the relationship between compressive strength and curing age of tested concrete. It should be noted that the control mixture of this experiment has 23.9 MPa and 27.9 MPa of compressive strength at 7 days and 28 days, respectively. The development of compressive strength increasFed with curing age normally. The results indicate that incorporating waste Bakelite at 3% and 5% levels enhances compressive strength, while the compressive strength of WB7V is marginally lower than that of the control mixture. However, an escalation in fiber content beyond 5% (i.e., 7%) results in a decrease in compressive strength, leading to inadequate compaction of the concrete. Therefore, it could be suggested that the addition of waste Bakelite 5% by volume is might suitable for utilization of waste Bakelite (bar shape) to improve compressive strength. The reason can be stated that the fiber bridging effect ceases transverse deformation increasing the compressive strength of concrete. On the other hand, adding fiber at a higher amount increases more voids in concrete, which results in reduction of the compressive strength (Mello *et al.*, 2014).

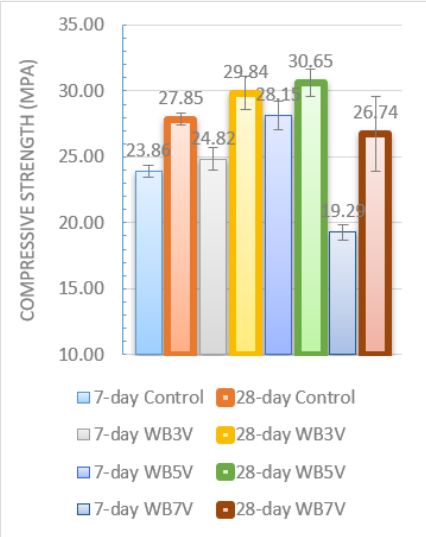


Figure 3. **Compressive Strength of Waste Bakelite Concrete**

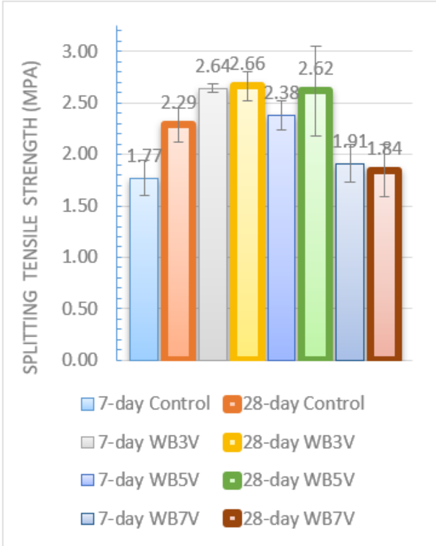


Figure 4. **Tensile Strength of Waste Bakelite Concrete**

Splitting Tensile Strength

This study experimentally investigated the tensile and flexural strength of waste Bakelite concrete. The splitting tensile test was conducted to obtain the tensile of the specimens. Figure 4 shows the tensile strength of the Bakelite concrete. The tensile strength at 7 and 28 days of control concrete were found to be 1.8 and 2.3 MPa, respectively. It should be noted that the tensile strengths of WB7V at 7 and 28 days are more or less the same with control concrete whereas WB3V and WB5V have higher tensile strength than that of the control concrete at all ages. It is interesting to note that tensile strength concrete increase 14% to 16% when waste Bakelite bar was added at the rate of 3% to 5% by volume of concrete into concrete. Therefore, approximately, 15% enhancement in split tensile strength of waste Bakelite concrete compare with plain concrete should be recorded.

Flexural Strength

Figure. 4 shows that the selected waste Bakelite can improve tensile strength. In the case of flexural strength, waste Bakelite could also improve flexural strength as shown in Figure. 5. Three percent of waste Bakelite added improve 7-day flexural strength while WB5V and WB7V show significantly higher modulus of rupture than that of control concrete at all ages. It can observe that increasing waste Bakelite increases 7 days-modulus of rupture whereas the optimum dose of waste Bakelite is 5% by volume for modulus of rupture at the age of 28 days.

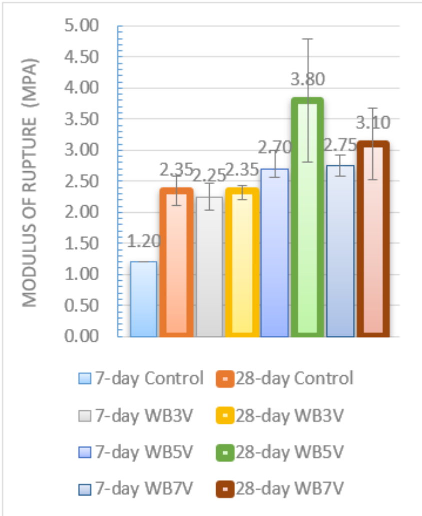


Figure 5. **Modulus of Rupture of Waste Bakelite Concrete**

Toxic observation by Colorimetric

Polyoxy benzy lmethy lengly colan hydride or Bakelite is a thermoset phenol-formaldehyde resin to be supplies which are proper for high durability applications. This material usually extruded or molded to be parts of vehicles, electric insulators for electrical appliance and heat insulators of kitchenware which is prepared from an elimination reaction of phenol with formaldehyde (Dharanidharan *et al*., 2015). Filler material namely calcium carbonate ($CaCO_3$) are added in this thermosetting polymer, consequently, Bakelite cannot be remolded as a typical recycle process. Landfilled or incinerated, which lead to environmental problems, are final designation of waste Bakelite (Kongkarat *et al*., 2011). Moreover, the existence of phenol as well as methyl and ethyl alcohols is toxic elements that can be leached into the environment from broke Bakelite. The leachate quality shows rise of oxidisability and presence of phenol in contaminated water. Therefore, disposal of waste Bakelite should be managed to avoid water contamination (Dharanidharan *et al*., 2015). When Bakelite is broken, the toxic substances become airborne and may cause inhalation, ingestion, or direct skin contact. Usahanunth and Tuprakay (2017) and Usahanunth *et al*. (2018) described that the concrete and the mortar are pink color when milled waste Bakelite was partially replaced as conventional aggregates, such as natural fine aggregate and natural coarse aggregate as shown in Figure 6(a) and Figure 6(b). This phenomenon displays that crushed waste Bakelite is source of phenol as well as formaldehyde in the concrete curing water. The concentration of the toxics are higher than standard of effluent water that specified by the ministry of industry (B.E. 2535 and B.E.2559). Otherwise, almost all waste Bakelite concrete specimens in this work are normal concrete colors as shown in Figure 6 (c). However, some pink color spots were found in some specimens which reveal that some of the waste Bakelite bars were broken during the mixing process. Certainly, the presence of phenol and formaldehyde in curing water in this research might significantly less than that of Usahanunth *et al*. (2018). From laboratory results, the phenol is not detected and 0.22 mg/L of formaldehyde is detected as ASTM D6303-98 in the curing water.

(a)

(b)

(c)

Figure 6. Waste Bakelite Concrete (a) from Usahanunth and Tuprakay (2017) (b) from Usahanunth *et al*. (2018) (c) from this research

Discussion

Since Bakelite is high durability and high strength material (200 MPa) due to the formation of cross-linked polymers (Sahajwalla *et al*., 2016), it is a highly performance product (high heat resistance and great chemical resistance) and high durability parts which are manufactured for various auto-related products due to the excellent properties achieved by its strong network bridge structure (HEXION, 2018; Sumitomo, 2018).

However, the awful decrease of compressive strength shows when adding milled waste Bakelite into concrete and mortar, especially replacing as fine aggregate. Therefore, this work demonstrates the utilization of waste Bakelite into concrete without adverse impact on workability and strength. Moreover, the result shows that concrete with waste

Bakelite as a fiber 3% and 5% slightly increase compressive strength (7% and 10%) whereas approximately, 15% enhancement in split tensile strength to unreinforced plain concrete was presented. Adding waste Bakelite at 5% by volume into plain concrete increases the modulus of rupture by 2.25 and 1.62 times at the ages of 7 and 28 days, respectively, due to a sufficiently high amount of random interlocking of the Bakelite at the crack area of the tested beam. In addition, an increase in fiber content beyond 5% (specifically, 7%), the compressive strength reduces. The presence of excess fibers contributes to the formation of voids, subsequently diminishing the internal strength of the concrete and leading to an overall reduction in compressive strength.

From a toxic point of view, Usahanunth *et al.* (2018) reported that the contamination of phenol and formaldehyde of all mixes except 20%-Waste Bakelite coarse aggregates replace (RNCA-20), phenol and formaldehyde were found higher than the standard by the department of industrial works, ministry of industry, B.E. 2535 (1992). However, according to the latest standard effluent water that specified by the department of industrial works, ministry of industry, B.E. 2559 (2016), all the mixture of them found higher than the standard. This work reveals that waste Bakelite should be used as the original form to avoid phenol and formaldehyde substance discharge from broken waste Bakelite.

Conclusions

Based on the results obtained from this research on the mechanical properties and the recommendations for the suitable application of selected waste Bakelite led to the following conclusions:

The addition of waste Bakelite 3% to 7% by volume into concrete give an insignificant negative effect on the workability which was measured by slump test. Then, no adverse effect from suitable adding waste Bakelite on the concrete workability was concluded in this work.

Concrete with waste Bakelite as a fiber 3% and 5% by volume slightly increase compressive strength (7% and 10%) whereas approximately, 15% enhancement in split tensile strength by bar and T shape as a fiber-reinforced concrete was found. Adding waste Bakelite 5% by volume into plain concrete improves modulus of rupture to be 2.25 and 1.62 times of that of plain concrete at the age of 7 and 28 days, respectively.

The results obtained in this study recommend that waste Bakelite should be used as the original form (should not mill or ground) to avoid phenol and formaldehyde substance discharge from broken waste Bakelite and to get the strength from waste Bakelite to improve mechanical properties of concrete. The Bakelite content exceeding 5% diminishes internal strength, causing an overall reduction in compressive strength.

Further studies are highly necessary to demonstrate the rate of toxic discharge from waste Bakelite as a fiber in concrete, and destruction of this waste Bakelite concrete.

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