CHAPTER 1
INTRODUCTION

1.1 Rationale/Problem Statement

The best known steam-cured materials are sand-lime brick and cellular concrete or autoclaved aerated concrete (AAC), in which the ingredients consist of very fine aggregate, lime, water and ordinary Portland cement (OPC) with aluminium powder as a pore-forming agent [1]. The air bubbles present in aerated concrete are generated from the reaction between metallic aluminium and calcium hydroxide in the form of hydrogen gas [2]. After moulding, high steam pressure at a temperature of 180-200°C is used to cure to improve strength as well as reduce shrinkage. The AAC has several advantages over conventional concrete in that it is lighter in weight due to the presence of air bubbles, and subsequent lower thermal conductivity and it has higher heat resistance, including being environmentally friendly in terms of less construction site waste and uses only 1/5 of the concentration of resources as compared to traditional concrete [3]. The drawback of AAC is that it has a lower strength than the standard concrete. However, this has opened the door for partly or wholly replacing sand and lime by industrial waste by-products [1, 2, 4-7].

In Thailand, rice is the most common agricultural product with approximately 25 million tons being produced each year, and thus, the by-product, which is called rice husk, from the milling of rice, is produced at about 5 million tons each year [8]. In general, rice husk is used as a fuel in biomass power plants or boilers of various industrial sectors to produce steam, which also generates the solid waste or rice husk ash (RHA) at the end of process. Most of the RHA is disposed of in landfill, and this tends to have an effect on the cost for waste management as well as causing environmental pollution. However, the chemical composition of RHA contains more than 90% silica oxide (SiO_2) which is highly reactive or amorphous, and is controlled by burning at 600-800 °C [9, 10]. Other important properties are low specific gravity and a high porous structure. In this regard, RHA shows good pozzolanic materials and can be used as construction materials in concrete for a reduction of the cost (waste management and resource consumption) and waste to the ecosystem.

Nowadays, the worldwide recycling of aluminium continuously increase because of the economical use of naturally occurring raw materials, recycled waste materials and energy saving. The black aluminium dross, represented as residue by-products from the aluminium recycling process, can recover metallic aluminium in the range of 12-18% [11]. During the recovery process, non-metallic residues (NMP) are generated, which are usually disposed of in landfills. The main compositions of NMP or aluminium-containing waste (AW) are aluminium oxide (alumina) and a small amount of metallic aluminium (3-5%) [12]. These compositions imply that AW can be used as an alumina source in cement production or can be used as a pore-formatting agent in lightweight aggregate or lightweight concrete.

The present study focuses on the utilization of two types of waste residues (RHA and AW) in the preparation of AAC. The RHA was used as an aggregate for sand replacement at the level of 25-100% by weight, while the AW was played as a pore-forming agent for aluminium powder replacement at 5-20% by weight of metallic aluminium. The optimum mix proportion, the effect of autoclaving time and temperature and the effect of AW fineness on the final AAC products were investigated.

1.2 Literature Review

1.2.1 Lightweight Concrete

Lightweight concrete has a density lower than 2200 to 2500 kg/m^3 [13]). The benefits of lightweight concrete are in terms of structural load-bearing and as acoustic and thermal insulation (0.2-1.0 W/mK) [14]. The methods to produce lightweight concrete can be separated into 3 methods. They are no-fines concrete, lightweight aggregate concrete and aerated concrete, with each name depending on the materials and method to make the lightweight concrete.

1.2.1.1 No-Fine Concrete (NFC)

No-fine concrete is made from cement, water and course aggregate concrete without fine aggregate (sand). This method can reduce density due to each particle of coarse aggregate being coated with a layer (up to about 1.3 mm) of cement paste, which bonds it close to particles in point-to-point contact to leave interstitial voids. These voids are interconnected to make a porous open-texture concrete. Therefore, the density of NFC depends on the type and grading of the aggregate. Normally, the aggregate/cement ratio of a lightweight aggregate of NFC is 3-8 which can result in a density in the range of 800-

1400 kg/m^3, while the normal aggregate/cement ratio is in the range of 6-10, producing densities of 1200-1900 kg/m^3 [15].

1.2.1.2 Lightweight Aggregate Concrete

This lightweight concrete is produced in a similar fashion to normal concrete. However, in lightweight aggregate concrete, the normal aggregate is replaced by lightweight aggregate to reduce the density. Lightweight aggregate can be classified into 3 types, which are natural aggregates (pumice, scoria, diatomite, etc.), by-product aggregates (fly ash, silica fume, blast furnace slag, etc.) and processed aggregates. Lightweight aggregates are often used to produced structure lightweight concrete due to good to excellent concrete-making properties and they can achieve a high strength with a reasonable cement factor [15].

1.2.1.3 Aerated concrete

Aerated concrete means that air voids are introduced into the cement paste to reduce its density. This type of concrete is known as cellular, aerated or foamed concrete [16]. These air voids are created by chemicals (metallic powders like Al, Zn, H_2O_2) or mechanical (foaming agent) [5], which were first produced in Sweden in the 1930's [13]. In the past, aerated concrete was used for building blocks, but today, it has been adjusted for many applications, such as floors and walls [17]. However, the most common way to create voids is by the use of aluminium powder, the chemical reaction is shown in Eq. 1.1.

$$2Al + 3Ca(OH)_2 + 6H_2O \rightarrow 3CaOAl_2O_3{\cdot}6H_2O + 3H_2(gas) \qquad (1.1)$$

The metallic aluminium reacts with calcium hydroxide or alkali to generate hydrogen gas to form bubbles. The speed at which the air bubbles form is critical to the success of the final aerated concrete product. The benefits of aerated concrete are lower bulk density (400-800 kg/m^3) [2], lower thermal conductivity and higher heat resistance than the traditional concrete, including the savings in materials and the potential for large-scale utilization of wastes, such as pulverized fuel ash [18]. However, aerated concrete still has some disadvantages, such as having a lower strength, a higher moisture content and higher shrinkage compared with standard concrete. These disadvantages can be improved by curing at high steam pressure (at 180-200°C for 14-18 h.) [19], which is called autoclaving.

1.2.1.3.1 Autoclave conditions

A main compound to strengthen the development of concrete is calcium silicate hydrate (CSH), which is made from a hydration reaction between tricalcium silicate (C_3S) or dicalcium silicate (C_2S) and water [20]. Normally, CSH is an amorphous or poor crystalline structure which has many formations depending on the amount of Ca/Si ratio. In autoclave conditions, CSH losses interlayer water by heating and forming a new crystalline compound. This can improve the strength and reduce the moisture content and drying shrinkage of the concrete. However, at this condition, the normal phase can form α-dicalcium silicate hydrate (α-C_2SH) through having a Ca/Si ratio of about 1.5-2.0 [21]. This crystalline product is porous and weak which is the reason for the compressive strength of the concrete being reduced. Therefore, reactive silica is commonly added to the cement to reduce the Ca/Si ratio and to form another crystallized phase, such as 1.1 nm tobermorite, which is a stronger product [6]. Thus, pozzolanic materials from by-products can be used as the source of silica.

1.2.2 Utilization of Waste in Autoclave Aerated Concrete

Using by-products, such as fly ash silica fume and blast furnace slag, in concrete has been done for many years as a means of disposing of and replacing cement or filler. These residues can enhance the properties of concrete, such as strength and water permeability. In Autoclave aerated concrete (AAC), which is also been made similar to normal concrete, but the main objective of the utilization of waste in AAC is to reduce density, including waste material recycling, reduce costs and save resource consumption and energy [18]. Therefore, the important property of residues is low weight rather than raw materials, such as sand or ordinary Portland cement (OPC).

According to Kurama *et al.* (2009) [1], who focused on coal bottom ash in AAC mixtures, the rapid reaction of dissolved silica in ash increased the tobermorite formation, which increased the strength with lower unit weight of AAC. Karakurt *et al.* (2010) [4] indicated that the coarser zeolite (0.5-1 mm) of up to 50% usage has been effective on the compressive strength and he also stated that fine zeolite (100 μm) needed a higher water requirement than coarse zeolite. Mostafa (2005) [2], used air-cooled slag (AS) to replace lime and sand, and observed that the use of slag can reduce the curing autoclaving time, as well as the amount of lime and sand. The optimum strength was achieved by 50% AS substitution of low-lime mixes (10% CaO), especially over a short time (2-6 h). Wongkeo and Chaipanich (2010) [6] investigated the incorporation of coal bottom ash and silica fume in aerated concrete mixtures and noted that the utilization of these by-products gave a relatively high strength compared with the reference at 28 days for normal curing and at 6 h for high steam pressure. While Holt and Raivio (2005) [17], utilized gasification residues as aggregate and pore-foaming agent. They found that the relatively high aluminium content in cyclone dust rather than filter dust caused the lower density of AAC, however, the reactivity of Al-containing residues is lower than aluminium powder.

1.2.3 Use of Rice Husk Ash in Concrete

The incorporation of RHA in concrete has been investigated for many years because of its properties as it has been shown to be a good pozzolanic material [9, 10, 22], as well as a lightweight material. The partial ordinary Portland cement (OPC) replacement by RHA could be attributed to volume concrete reduction, which occurs because of the hydration reaction [23]. In blended Portland cement, the RHA substituted for cement caused an improvement in the early compressive strength of concrete. However, the concrete incorporated RHA tends to have a relatively high water/binder (W/B) ratio compared with normal concrete, and this problem can be solved by using a superplatilizer agent [24]. Givi *et al.* (2010) [25], who studied the effect of the fineness of RHA (5 µm and 95 on µm) strength, water permeability and the workability of binary blended concrete, found that a decrease in particle size of RHA can enhance the strength and workability of concrete as well as reduce its water permeability. The ultimate strength of concrete occurred at 10% of RHA substituted ratio.

Moreover, the utilization of RHA with other residues, such as fly ash, and in another applications, such as lightweight aggregates, was also investigated. Chindaprasirt and Rukzon (2008) [26] used a ternary blend of ordinary Portland cement (OPC), ground RHA and classified fly ash (fine fly ash, FA) in concrete production to study the effect on the strength, porosity and corrosion resistance. Using a low level of residues (RHA and fly ash) the replacement ratio with blend cement played a significant role on strength improvement for long curing times. This effect corresponded to porosity loss and relatively high corrosion resistance compared with the reference. While the lightweight aggregate (LWA), which, prepared from fine RHA mixed with sodium hydroxide solution (NaOH), showed the low bulk density of 0.20-0.40 g/cm^3. The ground RHA-LWA had a better performance in the function of expansion, solubility and disintegration than the as-received RHA-LWA. However, the disintegration of LWA in boiling water was the main problem, which was alleviated by the incorporation of 2-7% boric acid by weight of RHA [27].

1.2.4 Application of Al-containing Waste (AW)

Aluminium dross represents a by-product from primary and secondary aluminium productions, which are classified according to their metal content into white and black dross, respectively. Low-quality dross produced by the secondary aluminium industry typically contains a mixture of aluminium oxides and slag with recoverable aluminium content ranging from 12-18% [11]. This treatment process generates the non-metal products called aluminium recycling waste (or AW for in this study) containing alumina salts, impurities and a small amount (3-5%) of metallic aluminium, which normally is disposed of in landfills. There have been previous research studies which have investigated the use of AW. Pickens and Morris (2001) [28] presented a process where aluminium recycling waste can be used to produce calcium aluminate by mixing with calcium oxide. This final product is used to remove undesirable elements, such as sulphur, in high-quality steel. In construction materials, Bajare et al. (2011) [29], prepared the expanded clay aggregate (ECA) by mixing aluminium scrap recycling waste and municipal solid waste (MSW) containing glass. Results found that the density of ECA depended on two factors: the amount of added aluminium recycling waste and sintering temperature. This implies that aluminium recycling waste acts as pore-forming agent can be used in AAC production.

1.3 Research Objectives

1. To determine the optimum mix proportions on the compressive strength and the dry density of AAC.
2. To study the effects of autoclaving time and temperature on the compressive strength, dry density, thermal conductivity and microstructure of AAC.
3. To study the effects of Al-containing waste fineness on the compressive strength, dry density and microstructure of AAC.

1.4 Scope of the Research

1. The rice husk ash used in this research was synthesized by an electric furnace in a laboratory at a temperature of 650°C for 1 hour.
2. Al-containing waste was collected from the aluminium recycling industry.

3. Rice husk ash was used to replace quartz sand at 25, 50 and 75 and 100% by weight, while aluminium powder was substituted by Al-containing waste at levels of 5, 10, 15 and 20% by weight of metallic aluminium.
4. The samples were moist cured for 7, 14 and 28 days, and the others were autoclaved at temperatures of 140, 160 and 180°C for 4, 8 and 18 h.
5. The fineness of Al-containing waste was classified into 3 different particle sizes, which were low, medium and high. Those particles retained on sieve no. 325 were greater than 45, between 45-34 and lower than 34%, respectively.
6. Compressive strength, dry density, microstructural, water absorption and thermal conductivity were examined.