CHAPTER II

LITERATURE REVIEWS

2.1 Glass-ceramics from zinc hydrometallurgy waste (Zn-waste)

In Thailand, utilization of Zn-waste from Padaeng industry Public Co., Ltd. into stable materials has been studied from previous researches [1,2]. Patarachao, B. studied about conversion of Zn-waste to glass-ceramic materials by design glass compositions by using Mixsoft Computer software. The other raw materials were added in order to adjust the oxide compositions of glass. The crystalline phase formation of each glass-ceramic depended on the compositions and the heat-treatment. The major phases found in glass-ceramics were quartz (SiO_2), cristobalite (SiO_2), pyroxene $(Mg_{0.937}Fe_{0.063})(Ca_{0.751}Na_{0.249}Fe_{0.018})(Si_2O_6)$, anorthite $(Ca(Al_2SiO_8)$, and wollastonite-ferroan $(Ca_{2.87}FeO_{0.13}(SiO_3)_3)$. The major factors that affected crystal phase formation were the compositions of each glass-ceramic and the heat-treatment temperatures. Glass-ceramics containing a single phase i.e. pyroxene or wollastonite-ferroan gave high bending strength, whereas glass-ceramics containing mixed phases gave lower strength. The maximum bending strength of glass-ceramics containing pyroxene phase heat-treated at 750°C for 1 hour and 850°C for 2 hours were ~119.26 MPa. The minimum bending strength of glass-ceramics containing mixed phases heat-treated at the same condition was ~22.96 MPa.

Kreethawate, L. studied about utilization of Zn-waste to develop of tiles and ceramic glaze. Zn-waste were mixed with traditional tile body and mixed with other raw materials in different proportions to study the effects of compositions on properties of tiles and glazes. For tiles production, the results exhibited that up to 70% of Zn-waste in tile composition provided acceptable properties for application. The bending strengths range from 61.6 MPa -107.26 MPa, which was at least double of the strength of specimen without Zn-waste (30 MPa). In the case of glazes preparation, the color shades of glazes slightly changed to darker with increasing amount of Zn-waste in glaze composition. The advantage of this study was a low cost and high percent of waste loading process.

In Europe, recycling of zinc hydrometallurgy waste in glass and glass-ceramic was studied by Pelino, M. [6]. Jarosite, an iron rich hazardous waste resulting from the hydrometallurgy of zinc ores, granite scraps, mud, and glass cullet were mixed together to produce glass and glass-ceramics which are suitable for tiles production. The fracture toughness of the glass-ceramics tiles was about 2.0 MPa $m^{1/2}$, which is higher than conventional ceramic tiles (~0.7 MPa $m^{1/2}$). Montanaro, L., et al. [7] focused on the recycling of red mud wastes from zinc hydrometallurgy for the production of porous building materials for heat and sound insulators.

2.2 Glass-ceramics from utilization of other wastes

Most of industrial wastes contained heavy metals which are toxic and hazardous to environment, thus, transformation of these wastes to more stable materials has been getting attention from many researches.

Fly ash is very popular to reuse as raw material for glass-ceramics production. Boccaccini, A. R., et al. studied about sintered glass-ceramics from incinerator fly ash. They studied sintering parameter in one and two schedules for the fabrication of glass-ceramics from glass powder. It was found that the best fabricated glass-ceramics were sintered for 6 hours at 1000°C after a holding time of 4 hours at 880°C [8]. Properties of the best obtained glass-ceramics i.e. density, hardness, thermal expansion (20-700°C), and fracture strength were 2.74 g/cm^3, 3.8 GPa, $6x10^{-6}$/C, and 88 MPa, respectively. Moreover, they also reported phase formation in the glass-ceramics [9]. It was found that the present phases were diopside, monoclinic wollastonite, and triclinic wollastonite. Phase formation is depended on time and temperature of heat treatment.

Barbieri, L., et al. [10] has been successfully mixed steel fly ash with municipal incinerator grate ash or glass cullet as glass-ceramic to produce stable and inert materials by controlling heat treatment of crystallization. All the glass-ceramics obtained have a good chemical durability and metallic micropollutants release in the range allowed by the Italian regulations. Thermal expansion decreased by introducing the steel ash in the starting batch because of the Zn modifier and Fe nucleating effect. The appearance of a different coloration (yellow, green, or brown) is depended on the amount of steel dust added in the system because of the high iron content, however, without substantially change of the thermal and mineralogical behaviors.

Normally, the properties of glass-ceramics depend on chemical compositions, thus, addition or mixing other materials in fly ash was also studied. Cheng, T. W. added $Mg(OH)_2$ and waste glass with fly ash as raw materials [11] resulted in significantly improved physical and mechanical properties. Moreover, it is higher chemical resistance compared to the one with incinerator fly alone. This glass-ceramics can be useful for engineering and construction applications. Moreover, fly ash can be mixed with blast furnace slag studied by Folgueras, M. V., et al. for the building materials application [12]. In their study, fly ash is not suitable to produce glass and glass-ceramics, thus, blast furnace slag was used as a base raw material for formulated glass.

In addition, slag from other industries such as blast furnace slag [13], steelwork slag [14], and iron-making slag [15] were also used as raw materials for glass-ceramics production. Jeremy, P. W., et al. produced glass-ceramics from a mixture of iron-making slag and waste-bottle glass in a 60:40 weight ratio. The iron-making slag contained high titanium oxide content (~34.3 wt %), therefore, glass-ceramics can be prepared by melting and subsequently annealing the parent glass at 600°C for 5 hours. The obtained glass-ceramics have high strength (101-184 MPa) because of very low porosity.

Glass-ceramics from the mixtures of coal ash and soda lime glass were studied as well. Francis, A. A., et al. [16,17] varied percentage of coal ash (40-100 wt%) in the composition. It was found that dendrites crystals in the specimens are hematite phase. Dendritic solidification occurred due to solidification heat, producing a negative temperature gradient in the glass adjacent to the magnetic crystals; this negative gradient leads to increasing degree of supercooling with increasing distance from the glass-crystal interface. The stability of the interface decreased and leaded to dendritic growth by thermal diffusion.

2.3 Glass-ceramics obtained by non-melting process

In order to save economic loss of two steps thermal process, glass-ceramics obtained from non-melting raw materials were studied. Glass-ceramics were produced from utilization of fly ash and waste glass by sintering process. Soon-Do Yoon and Yeon-Hum Yun [18,19] produced glass-ceramics by grinding the mixture of raw materials in disk type ball mill for 4 hours to get fine powder and subsequent sintering at various temperatures. The obtained glass-ceramics are suitable for industrial buildings, external and internal wall facings, and pavement materials. The maximum bending strength of glass-ceramics in their study was 150.3 MPa obtained from the mixture of 60 wt% of fly ash and 40 wt% of waste glass sintered at 1000°C. Besides, this technique can be produced porous glass-ceramics by polyurethane foam [20]. The polyurethane foam was added in the step of mixing raw materials (fly ash and waste glass) and decomposed during sintering. Bending strength of porous glass-ceramics was 6 MPa. It has potential for producing diffusers which could be used for water aeration.