

## Melting treatment of waste asbestos using mixture of hydrogen and oxygen produced from water electrolysis

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**Abstract**—In this study, we melted four types of waste asbestos containing material such as spread asbestos, plasterboard asbestos, slate asbestos and asbestos 99 wt%, in a melting furnace at 1,450-1,550 that uses a mixture of hydrogen and oxygen (Brown's gas) as a fuel. More volatile components (CaO, K<sub>2</sub>O) are enriched in spread asbestos, plasterboard asbestos, and slate asbestos, while less volatile compounds (SiO<sub>2</sub>, Fe<sub>2</sub>O<sub>3</sub>, MgO) remain in asbestos 99%. Through basicity of raw materials, spread asbestos, plasterboard asbestos, and slate asbestos were found to have more alkalinity, and asbestos 99% was found more acidic. SEM and EDX results revealed that all raw materials had various kinds of asbestos fiber. Spread asbestos, plasterboard asbestos, and slate asbestos were considered as tremolite asbestos, whereas asbestos 99% was considered as chrysotile asbestos. It was further confirmed by SEM and XRD studies that all waste materials contained some crystalline structures which transformed into amorphous glassy structure on melting. Also, in case of added glass cullet during the melting of spread asbestos, it transformed the raw material into a perfect vitrified product having more glassy surface and amorphous in nature.

Key words: Waste Asbestos, Brown's Gas, Basicity, Vitrification, Stabilization

### INTRODUCTION

Asbestos is a naturally occurring fibrous silicate mineral which comes in several forms. It includes chrysotile, amosite, crocidolite, tremolite asbestos, anthophyllite asbestos, actinolite asbestos, and any of these materials that have been chemically treated and/or altered [1,2]. Asbestos minerals have been used for a number of applications due to their excellent physical properties such as thermal insulation, chemical and thermal stability, and high tensile strength [3,4]. Due to these properties, these are being used as loose-fill insulations, acoustic and thermal sprays, pipe and boiler wraps, plasters, paints, flooring products, roofing materials, cementitious products and in a variety of other of building materials [5-8]. Asbestos consists of microscopic bundles of fibers and these fibers may get into the air. Asbestos materials were found to cause respiratory diseases associated with occupational and environmental exposure to asbestos fibers. Asbestos-related diseases usually involve lung cancer, asbestosis, and mesothelioma and can result in severe disability and fatality [9-20]. In 1975, the Environmental Protection Agency (EPA) regulated those materials that contain greater than 1% asbestos. Currently, use of asbestos products is either banned or very restricted [21-23].

The disposal of waste asbestos includes landfilling, thermal processes, chemical coagulation and immobilization. In this study, we melted four types of asbestos containing waste material such as spread asbestos, plasterboard asbestos, slate asbestos and asbestos 99 wt%, in a melting furnace at 1,450-1,550 °C that uses a mixture of hydro-

gen and oxygen (Brown's gas) produced from water electrolysis as a fuel. The morphology of melted slags was further studied by SEM and XRD.

### EXPERIMENTAL METHODS

The asbestos used in this study, such as spread asbestos, plasterboard asbestos, and slate asbestos, was collected from a building site at Haw Sung city (Kyung-ki Province, Korea). Asbestos 99% was collected from reagent ordering. Its capacity was 150 tons of asbestos containing materials per day. In the melting furnace, raw materials were burned in the combustion chamber at 1,450-1,550 °C and the flue gas was cooled through a waste heat boiler and treated

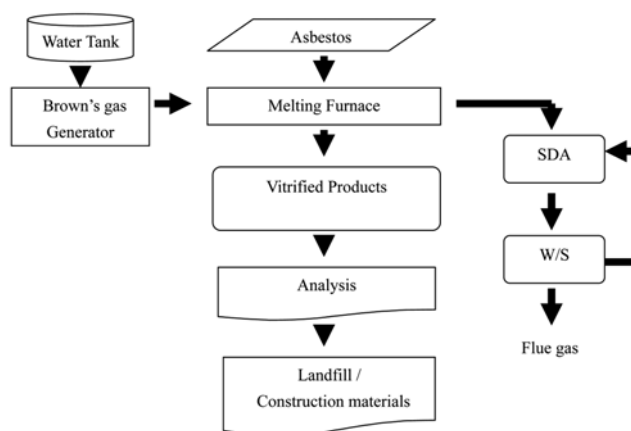


Fig. 1. Flow chart of asbestos process.

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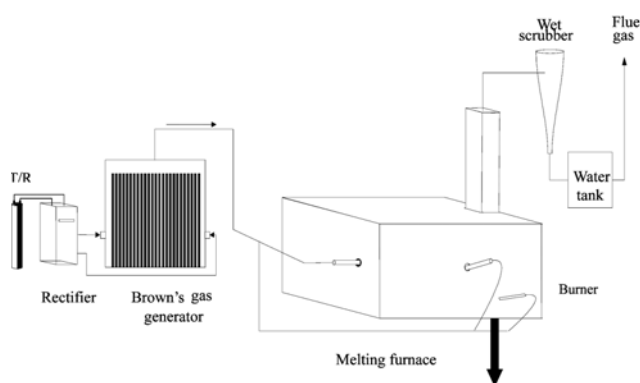


Fig. 2. Schematics of asbestos-melting system using Brown's gas.

through a spray-dry absorber and baghouse filter.

Raw materials (asbestos containing material) were melted in a melting furnace (E&E Company, Korea), which used Brown's gas, a stoichiometric mixture of atomic and molecular hydrogen and oxygen [24-26], as a fuel (Fig. 1) and can melt asbestos (5 t/d). Each batch was of about 100 kg of waste asbestos.

Brown's gas was generated by a Brown's gas generator (E&E Company, Korea) by electrolysis of water (Fig. 2). This generator produces 300 m<sup>3</sup>/h of Brown's gas and each burner consumes 25 m<sup>3</sup>/h of Brown's gas. The melting furnace contained three Brown's gas burners which were used simultaneously during melting. Each batch was of about 100 kg of waste asbestos. In case of spread asbestos, glass cullet (10 wt%) was used as additive to adjust the basicity of slag and as glass forming material.

The raw material (spread asbestos) and all slags were dried at 110 °C for 24 h. After drying, these were pulverized to a size of <300 µm and were screened through a size of 300 µm. The chemical compositions of these samples were analyzed by X-ray fluorescence (XRF). To confirm asbestos presence, all raw materials were examined via energy dispersive X-Ray spectrometer (EDX) and scanning electron microscopy (SEM). The morphology of all the raw materials and their slags was examined via X-ray diffractometry (XRD), by using CuK radiation and scanning electron microscopy (SEM).

## RESULTS AND DISCUSSION

### 1. Composition of Raw Materials (Asbestos Containing Material)

Raw materials, as received from the building site, were of different colors. The composition of these raw materials is shown in Table 1. Major components of the spread asbestos were CaO, SiO<sub>2</sub>, Al<sub>2</sub>O<sub>3</sub>, MgO and K<sub>2</sub>O; plasterboard asbestos contains CaO, SiO<sub>2</sub>, S, and MgO, slate asbestos contains CaO, SiO<sub>2</sub>, Fe<sub>2</sub>O<sub>3</sub> and MgO, whereas asbestos 99% contains SiO<sub>2</sub>, MgO, Fe<sub>2</sub>O<sub>3</sub> and CaO (Table 1). More volatile components (CaO, K<sub>2</sub>O) are enriched in spread asbestos, plasterboard asbestos, and slate asbestos, while less volatile compounds (SiO<sub>2</sub>, Fe<sub>2</sub>O<sub>3</sub>, MgO) remain in asbestos 99%. Ratio of alkaline CaO to acidic SiO<sub>2</sub> is known as basicity of these raw materials. Basicity of spread asbestos, plasterboard asbestos, and slate asbestos is 1.9, 8.85, and 5.79, respectively, due to large amount of CaO (57.11 wt%, 75.51 wt%, 71.62 wt%) and that of asbestos 99% is 0.02 due to SiO<sub>2</sub> (42.47 wt%).

Table 1. Chemical composition (wt%) of raw materials

| Item                           | Spread asbestos | Plasterboard asbestos | Slate asbestos | Asbestos 99% | Glass cullet |
|--------------------------------|-----------------|-----------------------|----------------|--------------|--------------|
| SiO <sub>2</sub>               | 29.91           | 8.53                  | 12.38          | 42.47        | 70.54        |
| CaO                            | 57.11           | 75.51                 | 71.62          | 1.01         | 9.50         |
| Al <sub>2</sub> O <sub>3</sub> | 4.82            | 0.75                  | 1.12           | 0.40         | 0.72         |
| Fe <sub>2</sub> O <sub>3</sub> | 1.59            | 2.52                  | 9.96           | 18.23        | 0.17         |
| K <sub>2</sub> O               | N.D.            | N.D.                  | N.D.           | N.D.         | 0.27         |
| Na <sub>2</sub> O              | 0.12            | 0.11                  | N.D.           | N.D.         | 14.25        |
| MgO                            | 3.72            | 2.21                  | 2.66           | 36.62        | 4.75         |
| P <sub>2</sub> O <sub>5</sub>  | 0.13            | 0.54                  | 0.34           | 0.24         | N.D.         |
| ZnO                            | N.D.            | N.D.                  | N.D.           | N.D.         | N.D.         |
| CuO                            | N.D.            | N.D.                  | N.D.           | N.D.         | N.D.         |
| MnO                            | 0.41            | N.D.                  | 0.64           | 0.33         | N.D.         |
| TiO <sub>2</sub>               | 0.89            | 0.70                  | 0.50           | N.D.         | N.D.         |
| NiO                            | N.D.            | N.D.                  | N.D.           | 0.53         | N.D.         |
| Y <sub>2</sub> O <sub>3</sub>  | 0.40            | N.D.                  | N.D.           | N.D.         | N.D.         |
| ZrO <sub>2</sub>               | 0.07            | N.D.                  | 0.06           | N.D.         | N.D.         |
| Cr <sub>2</sub> O <sub>3</sub> | N.D.            | N.D.                  | N.D.           | N.D.         | N.D.         |
| Zn                             | 0.02            | N.D.                  | N.D.           | N.D.         | N.D.         |
| Sr                             | 0.11            | 0.18                  | 0.10           | N.D.         | N.D.         |
| Ba                             | 0.17            | N.D.                  | N.D.           | N.D.         | N.D.         |
| Sn                             | N.D.            | N.D.                  | N.D.           | N.D.         | N.D.         |
| S                              | 0.51            | 8.87                  | 0.62           | 0.06         | N.D.         |
| Cl                             | 0.03            | 0.45                  | N.D.           | 0.09         | N.D.         |
| Sb                             | N.D.            | N.D.                  | N.D.           | N.D.         | N.D.         |
| Basicity*                      | 1.9             | 8.85                  | 5.79           | 0.02         | 0.135        |

\*Basicity=CaO/SiO<sub>2</sub>; N.D.: not detected; unit: wt%

### 2. Presence of Asbestos in the Raw Material

The asbestos presence in spread asbestos, plasterboard asbestos, slate asbestos, and asbestos 99% (raw materials) is shown in Figs. 3(a), (b), 4(a), (b), 5(a), (b), and 6(a), (b). In raw materials, asbestos is present as thin and elongated fiber form [27]. Also, all raw materials except spread asbestos appeared as aggregated structure. Asbestos 99% observed via SEM appeared thicker and bigger than other raw materials in the fiber form. All raw materials observed via EDX are shown in Figs. 3(c), 4(c), 5(c), and 6(c) and contain the main composition of asbestos fiber. EDX analysis shows that while spread asbestos, plasterboard asbestos, and slate asbestos contain more Mg, Si, and Ca and less Fe and had tremolite asbestos; asbestos 99% contains more Mg, Si and less Fe, and was found to have chrysotile asbestos [27].

### 3. Disappearance of Asbestos in the Raw Material Slags and their Morphology

The improved glassy surface and amorphous nature of the slag obtained from the vitrification of raw materials slags were further confirmed from SEM micrographs of slags, shown in Fig. 7, and their XRD spectra, shown in Fig. 8. In raw material slags, asbestos fibers disappeared by melting using Brown's gas. Vitrified slags have a highly dense aggregation and a tough glassy surface as observed via SEM for all the slags except spread asbestos slag (with glass cullet), whereas a smooth glassy surface is observed in spread asbestos slags (with glass cullet). Although the XRD spectra of raw materials indicate the presence of asbestos crystalline [28], XRD

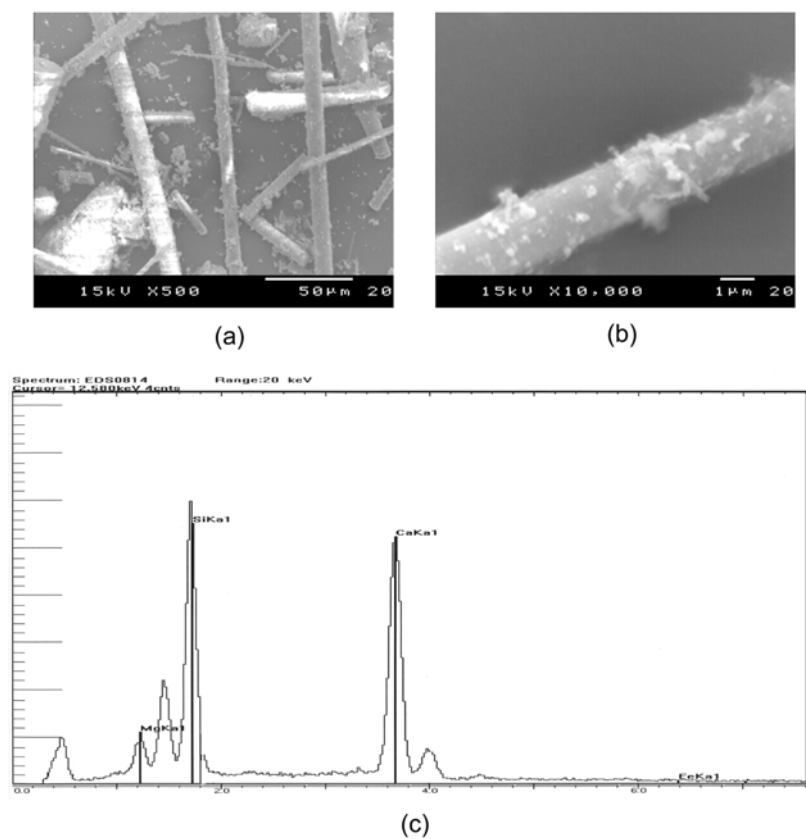


Fig. 3. Spread asbestos: (a) SEM photograph ( $\times 500$ ) (b) SEM photograph ( $\times 10,000$ ) (c) EDX spectrum.

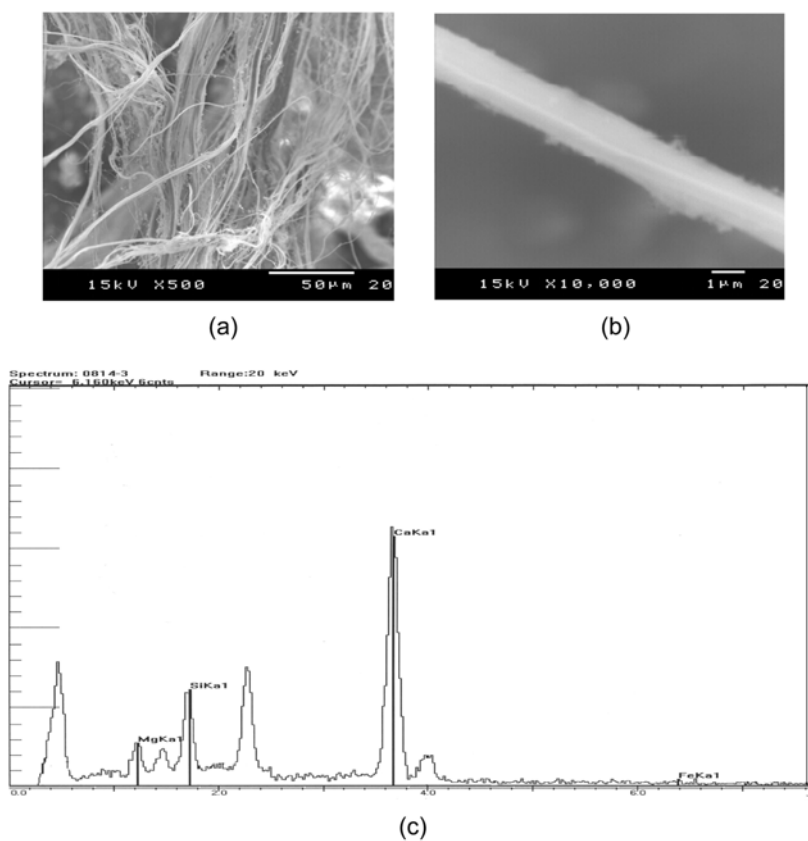


Fig. 4. Plasterboard asbestos: (a) SEM photograph ( $\times 500$ ) (b) SEM photograph ( $\times 10,000$ ) (c) EDX spectrum.

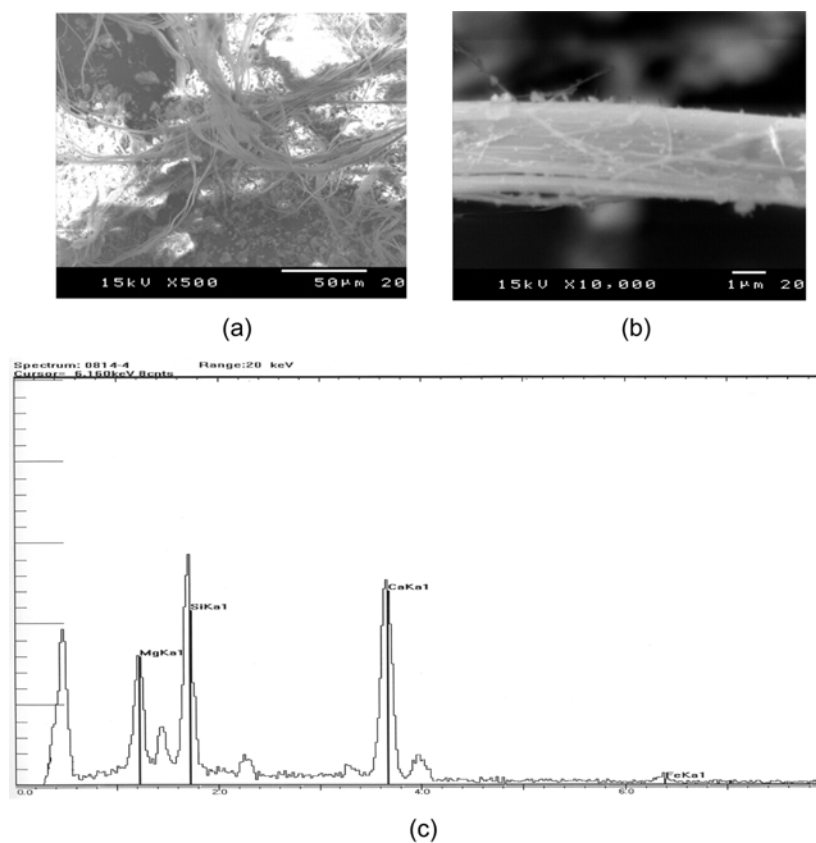


Fig. 5. Slate asbestos: (a) SEM photograph ( $\times 500$ ) (b) SEM photograph ( $\times 10,000$ ) (c) EDX spectrum.

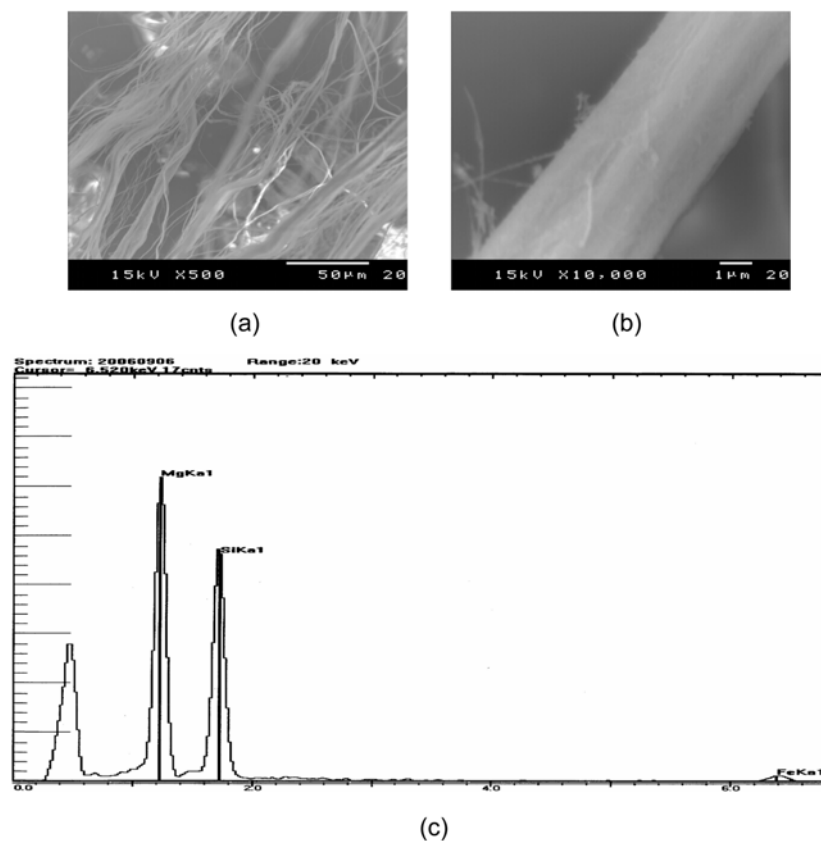


Fig. 6. Asbestos 99%: (a) SEM photograph ( $\times 500$ ) (b) SEM photograph ( $\times 10,000$ ) (c) EDX spectrum.

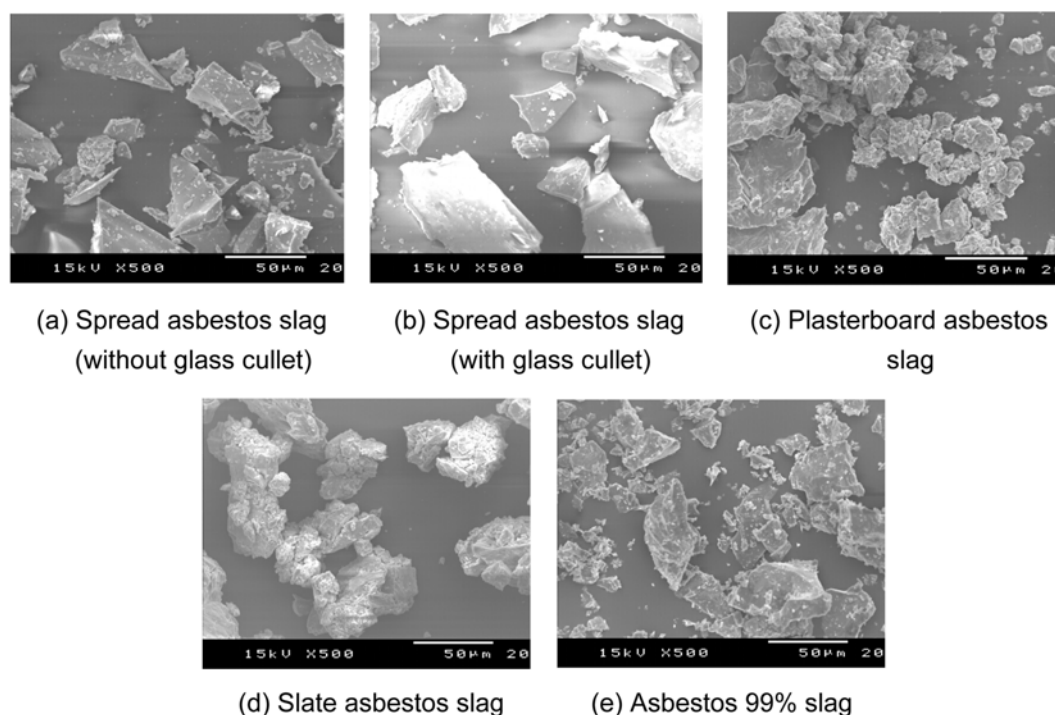


Fig. 7. SEM photographs of slag of raw materials.

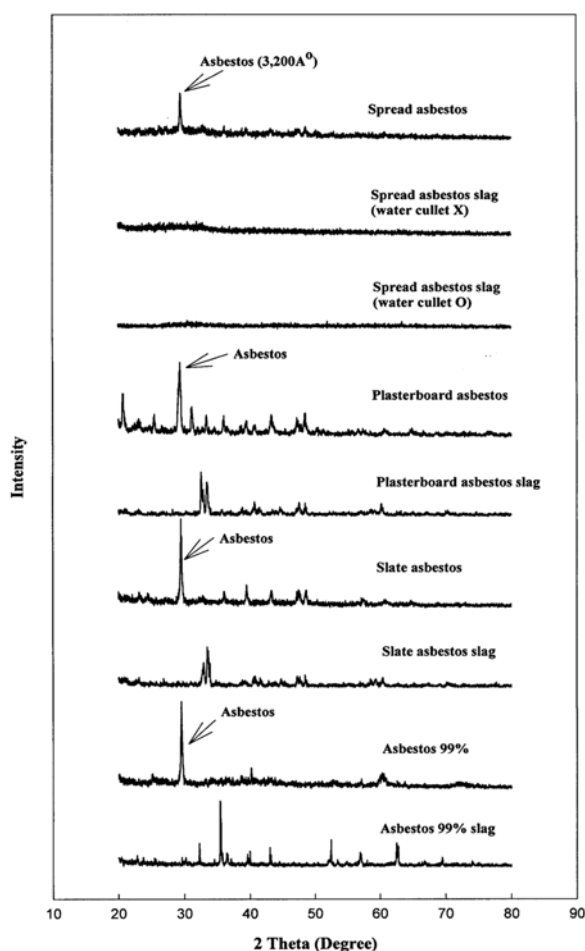


Fig. 8. XRD spectra of raw materials and their slag.

Table 2. The chemical composition of melted spread asbestos

| Item                           | Spread asbestos slag (without glass cullet) | Spread asbestos slag (with glass cullet) |
|--------------------------------|---|--|
| SiO <sub>2</sub>               | 29.99                                       | 48.44                                    |
| CaO                            | 57.22                                       | 32.70                                    |
| Al <sub>2</sub> O <sub>3</sub> | 1.82  | 1.37                                     |
| Fe <sub>2</sub> O <sub>3</sub> | 2.40  | 4.33                                     |
| K <sub>2</sub> O               | 0.00  | N.D.                                     |
| Na <sub>2</sub> O              | 4.19  | 0.15                                     |
| MgO                            | 1.10  | 1.23                                     |
| P <sub>2</sub> O <sub>5</sub>  | 0.61  | 0.52                                     |
| ZnO                            | N.D.  | 1.32                                     |
| CuO                            | N.D.  | 1.25                                     |
| MnO                            | 0.94  | 0.37                                     |
| TiO <sub>2</sub>               | 0.89  | 0.66                                     |
| NiO                            | N.D.  | 0.23                                     |
| Y <sub>2</sub> O <sub>3</sub>  | N.D.  | N.D.                                     |
| ZrO <sub>2</sub>               | 0.25  | 4.99                                     |
| Cr <sub>2</sub> O <sub>3</sub> | N.D.  | 0.33                                     |
| Zn                             | N.D.  | N.D.                                     |
| Sr                             | 0.2   | 0.17                                     |
| Ba                             | 0.39  | 1.07                                     |
| Sn                             | N.D.  | 0.14                                     |
| S                              | N.D.  | N.D.                                     |
| Cl                             | N.D.  | N.D.                                     |
| Sb                             | N.D.  | 0.26                                     |
| Basicity*                      | 1.91  | 0.68                                     |

\*Basicity=CaO/SiO<sub>2</sub>; N.D.: not detected; unit: wt%

patterns of vitrified slags confirm that the crystalline structure shifts to an amorphous structure [29].

#### 4. Effect of Basicity

The melted spread asbestos slag during melting changed its basicity to 1.91, shown in Table 2, and the addition of 3.5% (v/w) of water glass to the spread asbestos to make it palletized during melting changed its basicity to 0.68, because of the increase in its silica content to 48.44 wt%. Spread asbestos was then melted in a melting furnace at 1,450–1,550 °C for vitrification. The vitrified spread asbestos was dark gray with a rough surface and seemed to be a less vitrified product [30]. It was reported in the literature that CaO acts as a stabilizing agent and SiO<sub>2</sub> acts as a glass former [31], and that the amorphous or crystalline nature of the slag is dependent on the mass ratio of the CaO/SiO<sub>2</sub> (i.e., the basicity) of the slag [31,32]. Thus, because spread asbestos slag (without glass cullet) contains only a minor amount of silica, its melting does not lead to the production of glassy material [33–36]. Therefore, the effect of the basicity was examined by the addition of glass cullet to spread asbestos during melting in the furnace. When adding glass cullet, it was determined that the vitrified products had a glassy surface [33,34]. It was also reported in the literature that a lower basicity (0.24–1.24) leads to a more amorphous glassy matrix during the melting of raw material [29,37,38].

#### CONCLUSIONS

The vitrification of raw materials at 1,450–1,550 °C was successfully performed, for the first time, by using an energy-efficient Brown's gas. More volatile components (CaO, K<sub>2</sub>O) are enriched in spread asbestos, plasterboard asbestos, and slate asbestos, while less volatile compounds (SiO<sub>2</sub>, Fe<sub>2</sub>O<sub>3</sub>, MgO) remain in asbestos 99%. Basicity of spread asbestos, plasterboard asbestos, slate asbestos, and asbestos 99% is 1.9, 8.85, 5.79, and 0.02, respectively. Spread asbestos, plasterboard asbestos, slate asbestos were found to have more alkalinity and asbestos 99% was found more acidic. SEM and EDX results revealed that all raw materials had various kinds of asbestos fiber. Spread asbestos, plasterboard asbestos, and slate asbestos were found to have tremolite asbestos, whereas asbestos 99% was having chrysotile asbestos. SEM results of melted slags revealed that asbestos fibers of raw materials disappeared by melting with Brown's gas. XRD patterns of vitrified slags confirmed that the crystalline structure shifts to an amorphous structure. Addition of glass cullet during the melting of spread asbestos leads to a perfect glassy surface and more amorphous glassy matrix.

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#### REFERENCES

1. S. K. Thompson and E. Mason, *Chemical Health and Safety*, **9**, 21 (2002).
2. B. E. Tylee, L. S. T. Davies and J. Addison, *Annals Occup. Hygiene*, **40**, 711 (1996).
3. V. L. Kinnula, *Pathophysiology*, **5**, 107 (1998).
4. L. Bonneau, H. Suquet, C. Malard and H. Pezerat, *Environ. Res.*, **41**, 251 (1986).
5. W. Chromy, J. Naumann and M. Bandmann, *Tunnelling Underground Space Technol.*, **21**, 279 (2006).
6. R. Szweida, *Sealing Technol.*, **2001**, 6 (2001).
7. T. Feric, R. Krstulovic, J. Peric and P. Krolo, *Cement Concrete Comp.*, **19**, 301 (1997).
8. T. Feric, R. Krstulovic, P. Krolo and D. Toncic, *Hemjska Industrija*, **39**, 118 (1985).
9. R. Rudd, *Medicine*, **32**, 111 (2004).
10. Y. Liu, P. Zhang and F. Yi, *Lung Cancer*, **32**, 113 (2001).
11. D. Liddell, *Annals Occup. Hygiene*, **45**, 329 (2001).
12. K. Browne, *Annals Occup. Hygiene*, **45**, 327 (2001).
13. F. D. K. Liddell, *Annals Occup. Hygiene*, **45**, 341 (2001).
14. M. Tiitola, L. Kivisaari, M. S. Huuskonen, K. Mattson, H. Koskinen, H. Lehtola, A. Zitting and T. Vehmas, *Lung Cancer*, **35**, 17 (2002).
15. C. B. Manning, V. Vallyathan and B. T. Mossman, *Int. Immunopharmacology*, **2**, 191 (2002).
16. R. L. Attanoos and A. R. Gibbs, *Current Diagnostic Pathology*, **8**, 373 (2002).
17. F. Cappelletto and E. Merler, *Social Science Medicine*, **56**, 1047 (2003).
18. M. Erdinc, E. Erdinc, G. Çok and M. Polatli, *Environ. Res.*, **91**, 151 (2003).
19. N. H. D. Klerk, A. W. Musk, S. C. Pang and H. G. Lung, *Lung Cancer*, **18**, 236 (1997).
20. E. W. Kiritani, *Medical Hypotheses*, **33**, 159 (1990).
21. L. V. Harris and I. A. Kahwa, *Sci. Total Environ.*, **307**, 1 (2003).
22. J. Watts, *The Lancet*, **360**, 1230 (2002).
23. A. Budgen, *Lung Cancer*, **45**, 577 (2004).
24. Y. Brown, US Patent, 4,014,777 (1977).
25. Y. Brown, US Patent, 4,081,656 (1978).
26. H. K. J. Oh, *Mater. Process. Technol.*, **95**, 8 (1999).
27. J. H. Han, K. J. Kim, Y. H. Chung, J. Y. Lee, Y. M. Lee, H. K. Jung and I. J. J. Yu, *Korea Soc. Occup. Environ. Hygiene*, **11**, 102 (2001).
28. Y. Onal, E. Yakinci, T. Seçkin and M. G. Içduygu, *Colloids and Surfaces A: Physicochem. Eng. Aspects*, **255**, 27 (2005).
29. C. T. Li, Y. J. Huang, K. L. Huang and W. J. Lee, *Ind. Eng. Chem. Res.*, **42**, 2306 (2003).
30. Y. J. Park and J. J. Heo, *Hazard. Mater.*, **91**, 83 (2002).
31. L. Barbieri, A. C. Bonamartini and I. J. Lancellotti, *European Ceramic Soc.*, **20**, 2477 (2000).
32. K. Park, J. S. Hyun, S. Maken, S. Jang and J. W. Park, *Energy Fuel*, **19**, 258 (2005).
33. S. Maken, J. S. Hyun, J. W. Park, H. C. Song, S. Lee and E. H. Chang, *J. Sci. Ind. Res.*, **64**, 198 (2005).
34. J. S. Hyun, J. W. Park, S. Maken and J. J. Park, *J. Ind. Eng. Chem.*, **10**, 361 (2004).
35. T. H. Kwak, S. Lee, J. W. Park, S. Maken, Y. D. Yoo and S. H. Lee, *Korean J. Chem. Eng.*, **23**, 954 (2006).
36. T. H. Kwak, S. Maken, S. Lee, B. R. Min, J. W. Park and Y. D. Yoo, *Fuel*, **85**, 2012 (2006).
37. L. Barbieri, A. Corradi and I. J. Lancellotti, *Eur. Ceramic Soc.*, **20**, 1637 (2000).
38. K. E. Haugsten and B. Gustavson, *Waste Manage.*, **20**, 167 (2000).