Decomposition of asbestos materials using fluoride wastes

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Abstract. Asbestos is one of the materials causing ecological stress. Due to its health harmfulness, an effective, ecological, and economic decomposition is highly desirable. One of the decomposition possibilities is a chemical decomposition, which could compete with commonly used thermal decomposition. The chemical decomposition can be accomplished both with the use of pure chemicals and waste chemicals from production technologies. This work deals with the use of technological wastes containing hydrofluoric acid or fluorides. Fluorides release hydrofluoric acid in the acid medium, which acts as the main decomposition medium. The source of fluorides was waste from the glass and metallic material industry. The efficiency of degradation processes was studied by mass analysis. Materials and decomposition products were characterized by X-ray powder diffraction.

1. Introduction

Asbestos belongs to natural silicate minerals with a fibrous structure. It can be found in two mineral subgroups in nature – amphiboles and serpentines. The serpentinites are the largest asbestos group, where it is mainly found as chrysotile, which occurs in approximately 95% of industrial products. Materials with asbestos fibres were massively used thanks to their thermal and chemical resistance. These materials found use mainly in civil engineering, where they were used for the production of gaskets, ropes, pipes, boards, and roofing [1, 2].

The positive attributes of these materials are accompanied by big drawbacks in the form of negative influences on living beings and carcinogenicity. Asbestos is rated as a first-class carcinogen in the present day. Asbestos fibres are the main danger that can cause serious illnesses when inhaled. For this reason, the usage of these materials is forbidden. Manipulation and disposal of materials with asbestos contents is governed by “The law about chemical compounds and mixtures”, Act no. 350/2011 Sb. [3, 4].

A large amount of waste with these harmful fibres causes ecological stress. Effective disposal or at least conversion of asbestos fibres to harmless and useful materials is the aim of many researchers. Various disposal methods for these materials are already in use.

One of these methods is the thermal disposal of asbestos fibres, which is done in high temperatures (approx. 1000°C). Thanks to the high temperature, the bound water is liberated, and asbestos forms non-fibrous structures [5, 6, 7]. Another quick and effective method is microwave decomposition, where thanks to the higher temperature generated inside the material, the fibrous structures degrade into harmless and further useful magnesium trisilicate [8]. High energy grinding is one of the possible mechanical disposals [9].

Significant opportunities lie in the chemical disposal of these materials. Alkaline, organic, and inorganic acids or waste solutions from various technologies can be used as decomposition mediums.
In research papers of foreign authors, mixtures of sulphur and calcium hydroxide in combination with ball grinder were used \cite{10}. Solutions of phosphoric acid \cite{11}, oxalic acid \cite{12}, or mixtures of HCl and HF from warm freon decomposition were also used \cite{13}. Some other acids, such as acetic, hydrochloric, sulphuric, or hydrofluoric acids, can be used as decomposition mediums. The use of these acids as decomposition medium has been studied in the work Necasova K. et al. \cite{14}.

Hydrofluoric acid and its salts are very prospective mediums for the decomposition of asbestos materials because the acid very readily reacts with the silicon in the asbestos structure and thus disrupts the fibrous nature of this material \cite{15}. Waste with these acid precursors can be used for these applications. Some of the sources of this waste are glass, fluoride pesticides or metallic materials industry \cite{16}. The city and industrial wastewater which are contaminated by this compound can also be the sources. According to the research of Jiang K. et al. \cite{17}, we can get 70% pure calcium fluoride in the form of sand from this water by multistep crystallization. Fluorides have a wide range of uses. They are commonly used in the manufacture of grease, colours, ceramics, and polymers. For example, sodium fluoride is used for drinking water treatment. Other applications of NaF may include glass and porcelain enamel production or glue, insecticide, and timber protective varnish manufacture. It has its place in metallurgy, steel, and aluminium manufacture, where it is used as a fluxing agent. Fluorides are further used in the cosmetic and pharmaceutical industry. They are found in dental paste and mouth wash as protection against dental cavities. It is also added to drugs combating cancer or skin conditions. Fluorides in small quantities are essential for humans. In higher quantities, they can cause serious illnesses, for example fluorosis. Even the hydrofluoric acid has a range of uses, mainly in the glassmaking industry, in aluminum fluoride making, as an additive for swimming pools, freons, and chemical syntheses \cite{18}. Hydrofluoric acid and fluorides are generally marked as dangerous substances, except for water dissolved calcium fluoride \cite{19}.

2. Experimental

2.1. Materials and methods

We used samples of four different types of waste for this series of asbestos decomposition experiments: asbestos rope, wool, disc and roofing (figure 1). These samples were initially used as a gasket material and thermal insulation. The roofing sample comes from the roof of a holiday cottage.

A) B)
Figure 1. A) Asbestos rope sample; B) Asbestos roofing sample; C) Asbestos wool sample; D) Asbestos disc sample.

All materials were characterized by X-ray powder diffraction analysis (XRD) which was carried out on Bruker D8 Advance apparatus with Cu anode (λKα = 1.54184 Å) and variable divergence slits at Θ-Θ Bragg-Brentano reflective geometry. For the measurement, we used original asbestos rope and asbestos disc samples. Samples of asbestos roofing and wool were dissolved in 35% hydrochloric acid. All samples were analyzed on zero background sample holder in an alcohol medium. The measurement results of asbestos rope, roofing, wool and disc are shown in figure 2.
The results of asbestos rope analysis show the material is composed of chrysotile and talc. Chrysotile is an asbestos material \((\text{Mg}_3\text{Si}_2\text{O}_5(\text{OH})_4)\), and talc is a hydrated magnesium silicate \((\text{Mg}_3\text{Si}_4\text{O}_{10}(\text{OH})_2)\). Asbestos wool is composed of minerals cummingtonite and quartz. The asbestos disc is composed of minerals chrysotile, lizardite and other identified mineral in the sample is quartz. According to the results, the asbestos roofing is composed of cummingtonite, quartz and rankinite. Cummingtonite is a material consisting of magnesium silicate hydroxide \((\text{Mg}_7\text{Si}_8\text{O}_{22}(\text{OH})_2)\), and quartz is silicon dioxide \((\text{SiO}_2)\). Rankinite is a calcium silicate \((\text{Ca}_3\text{Si}_2\text{O}_7)\), and lizardite is a hydroxide magnesium silicate \((\text{Mg}_3(\text{Si}_2\text{O}_5)(\text{OH})_4)\).

The decomposition experiments were carried out at laboratory temperature (approx. 22°C) in one month. The decomposition was done in plastic closable containers, in which we placed a precisely weighted sample and a decomposing agent. The first used decomposing agent was a waste etching solution (ES) from the glassmaking industry, which contains residues of hydrofluoric acid and its salts. The second decomposing agent was a degreasing solution (DS), used for degreasing and cleaning of components before surfacing, mainly plating. We can also find residues of hydrofluoric acid and its salts in this solution. To increase the efficiency, small amounts of inorganic acids were added to the decomposing agents: sulphuric, phosphoric, hydrochloric and nitric acid. The decomposing agent was added to the sample in 1:7 ratio. The supportive inorganic acids were added in 1:5 ratio to the decomposing agent. Decomposition products were characterized by X-ray powder diffraction analysis too. The presence of asbestos minerals in the decomposition product was verified.

3. Results and discussion

3.1. Decomposition in the etching solution and its mixtures
Results of asbestos material decomposition in an etching solution (ES) and mixtures of ES and inorganic acids are shown in table 1 and discussed in the following chapters.
The ES disrupted the rope structure, released the end fibres and decomposed a small amount of asbestos fibres. The reaction of a decomposing agent with the asbestos wool caused most of the fibres to decompose and it created grey solid matter with thin translucent layer (calcium sulphate – CaSO₄·2H₂O and quartz SiO₂ by results XRD). The asbestos disc sample shows a disruption of the surface and an overall increase of porosity with a fibre release. The asbestos roofing sample shows only a change in colour. The results of the decrease of the mass of the samples are shown in table 1.

The decomposition mixture of ES with sulfuric acid disrupted the woven structure of the asbestos rope and partially decomposed the end of the fibres. The mass loss was 79.4%. (figure 3) The asbestos wool shows a nearly complete decomposition of the fibres confirmed by the mass decrease of 95%. The disc shows a complete decomposition of the outer shell and partial disruption of the fibres (mass decrease of 100%). The asbestos roofing shows disruption and swelling of the whole structure and creation of white solid phase. The solid phase was gypsum – CaSO₄·2H₂O, calcium sulfide anhydrite - CaSO₄ and quartz SiO₂ by results XRD, and it distorts the results of the mass analysis (see table 1).

| Decomposition Agent   | Sample            | Mass after decomposition [%] |
|-----------------------|-------------------|------------------------------|
| Etching solution      | Rope              | 17,7                         |
| ES                    | Asbestos wool     | -35,3                        |
|                       | Asbestos disc     | -0,4                         |
|                       | Roof tile         | -0,7                         |
| Sulfuric acid ES + H₂SO₄ | Rope              | 79,4                         |
|                       | Asbestos wool     | 95                           |
|                       | Asbestos disc     | 100                          |
|                       | Roof tile         | -49,7                        |
| Phosphoric acid ES + H₃PO₄ | Rope              | 19,4                         |
|                       | Asbestos wool     | 74,3                         |
|                       | Asbestos disc     | 53,2                         |
|                       | Roof tile         | -3,2                         |
| Hydrochloric acid ES + HCl | Rope              | 73,3                         |
|                       | Asbestos wool     | 92,0                         |
|                       | Asbestos disc     | 75,0                         |
|                       | Roof tile         | 48,5                         |
| Nitric acid ES + HNO₃ | Rope              | 80,8                         |
|                       | Asbestos wool     | 95                           |
|                       | Asbestos disc     | 82,2                         |
|                       | Roof tile         | 86,7                         |

Table 1. Mass decrease of the decomposed material.
The decomposition mixture of ES with phosphoric acid caused a complete disruption of the woven structure, thinning and a decomposition of a part of the asbestos fibres (mass decrease of 19.4%). One-tenth of fibres in the asbestos wool withstood the decomposition agent, mass decrease was 74.3%. The mixture caused the asbestos disc to change colour, a strong disruption of the surface and a mass decrease of 53.2% were also observed (figure 3). No longer fibres were seen in the sample. The asbestos roofing shows disruption of surface and crystallisation of white solid phase. The solid phase was probably a mix of gypsum – CaSO₄·2H₂O, clinochlore – Mg₅Al(AlSiO₃O₁₀)(OH)₈ and quartz – SiO₂ by results XRD.

The decomposition mixture of ES with hydrochloric acid had a strong degradation effect on all of the tested samples. It completely disrupted the woven structure and thinned the fibres of the asbestos rope sample. The mass decrease was 73.3%. In the case of the asbestos wool, it almost completely decomposed all the fibres (mass decrease of 92%). It decomposed the filling of the asbestos disc, thinned the fibres and decomposed small amount of them, the mass decrease was 75%. The whole structure of the asbestos roofing was disrupted by the agent and there are no visible fibres in the rest (mass decrease of 48.5%) (figure 3).

The decomposition mixture of ES with nitric acid caused thinning and release of the fibres in the woven structure of the asbestos rope (mass decrease of 80.8%). In case of the asbestos wool, it caused a complete decomposition of the fibres, which is confirmed by 95% decrease in the mass of the sample. The sample of asbestos disc showed a change of colour to grey, complete disruption of surface with a small change in overall size (mass decrease of 82.2%). The agent caused a complete disintegration of the asbestos roofing sample (mass decrease of 86.7%). The remaining solids contained no fibres.

Samples were characterized by X-ray powder diffraction analysis to evaluate the hazardous properties of the decomposed material residues. Some samples could not be measured due to a very small amount of a representative sample. The presence of asbestos minerals in the samples was recorded in table 2.

Figure 3. Decomposed sample of asbestos A) rope; B) disc; C) roofing.
Table 2. Contain asbestos minerals and other minerals in the decomposed material.

| Decomposition agent | Sample   | Other minerals                          | Asbestos mineral |
|---------------------|----------|----------------------------------------|------------------|
| Etching solution ES | Rope     | orthoclase                             | no               |
|                     | Wool     | jakobsite, Fe- compound                | no               |
|                     | Disc     | ankerite, NH₄MgAlF₆                   | no               |
|                     | Roof tile| -                                      | -                |
| Sulfuric acid ES + H₂SO₄ | Rope     | -                                      | -                |
|                     | Wool     | -                                      | -                |
|                     | Disc     | quartz                                 | no               |
|                     | Roof tile| gypsum, rankinite, orthoclase, quartz  | no               |
| Phosphoric acid ES + H₃PO₄ | Rope     | bayerite, orthoklase                   | no               |
|                     | Wool     | -                                      | -                |
|                     | Disc     | quartz, ankerite, NH₄MgAlF₆            | lizardite        |
|                     | Roof tile| quartz, sylvite, magnetite             | no               |
| Hydrochloric acid ES + HCl | Rope      | quartz                                 | chrysotile       |
|                     | Wool     | -                                      | -                |
|                     | Disc     | quartz, ankerite, NH₄MgAlF₆            | no               |
|                     | Roof tile| -                                      | -                |
| Nitric acid ES + HNO₃ | Rope      | no                                     | chrysotile       |
|                     | Wool     | quartz                                 | no               |
|                     | Disc     | illite, muskovite, quartz              | no               |
|                     | Roof tile| meniaylovite, quartz                   | no               |

In table 2, we can see that only 3 of 13 samples contained any asbestos mineral after the decomposition. Disc in decomposition agent ES + H₂PO₄, rope in agent ES + HCl and rope in agent ES + HNO₃. The residues of these three samples remain a hazardous waste. Other samples in decomposition reagent ES (and its combinations with acids) don’t contain asbestos minerals. These decomposition residues are not dangerous and may be reusable. For example, in the building industry. Because decomposition products as an accompanying mineral most often contain quartz, other aluminosilicates and minerals (see table 2).

3.2. Decomposition in degreasing solution and its mixtures

Results of asbestos material decomposition in degreasing solution (DS) and mixture of DS and inorganic acids are presented in table 3 and discussed in following chapters.
Table 3. Mass decrease of the decomposed material.

| Decomposition Agent | Sample       | Mass after decomposition [%] |
|---------------------|--------------|-----------------------------|
|                     | Rope         | 17,1                        |
|                     | Asbestos wool| 4,2                         |
|                     | Asbestos disc| 1,5                         |
|                     | Roof tile    | -0,1                        |
| Sulfuric acid       | Rope         | 31,3                        |
| $DS + H_2SO_4$      | Asbestos wool| 42,0                        |
|                     | Asbestos disc| 15,2                        |
|                     | Roof tile    | 16,4                        |
| Phosphoric acid     | Rope         | 41,3                        |
| $DS + H_3PO_4$      | Asbestos wool| 62,1                        |
|                     | Asbestos disc| 21,1                        |
|                     | Roof tile    | -66,3                       |
| Hydrochloric acid   | Rope         | 34,0                        |
| $DS + HCl$          | Asbestos wool| 14,3                        |
|                     | Asbestos disc| 72,7                        |
|                     | Roof tile    | 49,9                        |
| Nitric acid         | Rope         | 38,5                        |
| $DS + HNO_3$        | Asbestos wool| 42,6                        |
|                     | Asbestos disc| 50,5                        |
|                     | Roof tile    | -25,7                       |

Thanks to DS, we can see only a release of end fibres in the case of the asbestos rope sample. The reaction of the decomposing agent with the asbestos wool caused caking of the material and the decomposition of very small amount of fibres. After the experiment, the asbestos disc shows a disruption of the surface and release of a small amount of fibres. The sample of asbestos roofing shows a change in colour, a partial surface decomposition, and a fibre release. All of the mass decrease data are shown in table 3.

The mixture of DS and sulphuric acid caused the asbestos rope to harden, and disruption in the end fibres was observed (mass decrease of 31.3%). The asbestos wool sample was partially decomposed, which was shown by the mass reduction of 42%. But there were still some long visible fibres resisting the rest of the material, which turned tangled and dark grey. The disc sample disintegrated and formed a white solid phase with fibres. The mass decrease was only 15.2%. Concerning the asbestos roofing sample, there was discolouration and a surface disruption (mass decrease of 16.4%).

When using a mixture of DS and phosphoric acid, the asbestos rope shows partial disruption of the woven structure. Further, there was a decomposition of a small amount of fibres (mass decrease of 41.3%) and creation of fine firm matter, formed by bayerite – Al(OH)$_3$, and orthoclase – KAlSi$_3$O$_8$ according to XRD results. The asbestos wool shows a mass decrease of 62.1%, but the remains still contain long fibres. The asbestos disc sample was disintegrated into a grey solid matter with fragments of fibres, as shown in figure 4 (mass decrease of 21.1%). The asbestos roofing sample shows a change...
of colour and a disruption of structure. There was a white decomposition by-product which distorts
the mass reduction results (the mass increase of 66.3%). This by-product was combination quartz – SiO₂,
sylvite – KCl and magnetite – Fe₃O₄ (according to XRD analysis), which caused the increase
in the weight of the tested sample.

![Figure 4. Decomposed sample of asbestos A) disc; B) roofing; C) wool.](image)

The mixture of DS and hydrochloric acid freed up the end fibres of the asbestos rope and partially
decomposed them, which is shown by the change of their thickness and a mass decrease of 34%. The
remaining woven structure hardened. In a reaction with the asbestos wool, there was a minimal
visual decrease in the amount of fibres and only a small amount of fibres were decomposed (mass
decrease of 14.3%). The rest was composed of grey airy matter with fibres. The decomposing agent
strongly disrupted the surface of the asbestos disc and decomposed some fibres (mass decrease
of 72.7%). Concerning the sample of the asbestos roofing, there is a change in size, surface and colour.
There is also a large amount of white solid matter which doesn’t contain any fibres and devalues
the mass decrease result (mass decrease of 49.9%, see figure 4).

In the asbestos rope sample, there was a disruption of the surface and the woven structure. Further,
there was a thinning and a release of a small amount of fibres. The mass decrease of this sample was
38.5%. The asbestos wool sample shows a mass reduction of 42.6%, but there are long visible fibres in
the rest comprised of grey airy matter. (figure 4) The asbestos disc sample was disintegrated into grey
solid matter with a small amount of thin fibres (mass decrease of 50.5%). There was a change of colour
and a disruption of structure in the roof tile. There was a white decomposition by-product on the surface
again. This by-product could be a combination meniaylovite – Ca₄[(SO₄)(SiF₆)(AlF₆)]F·12H₂O and
quartz – SiO₂ (by XRD results). The results of the mass analysis and mass decreases are shown in table
3.

Samples were characterized by X-ray powder diffraction analysis to evaluate the hazardous
properties of the decomposed material residues too. Some samples could not be measured due
to a minimal amount of a representative sample. The presence of asbestos minerals in the samples was
recorded in table 4.
In table 4, we can see that 10 of 18 samples contained some asbestos minerals after the decomposition. All asbestos wool samples contain asbestos after decomposition, specifically cummingtonite. Further, the residues of decomposition of disc in agent ES + HCl, rope in decomposition agent DS + HNO₃ and agent ES + H₂SO₄. Roof tile in agent ES + HNO₃ and in agent DS samples contained asbestos. The residues of these 10 samples remain a hazardous waste. The decomposition medium used was not sufficient to break up the structure of asbestos materials. Other samples in decomposition reagent ES (and its combinations with acids) don’t contain asbestos minerals. These decomposition residues were not dangerous and may be reusable in the building industry as decomposition products ES media. Other minerals contained in the decomposition products are listed in the table 4.

Generally, it can be said that each material needs a different decomposing agent. For the description of the decomposition rope sample process efficiency, it can be said that the surface was disrupted, and the fibres were released. Concerning the asbestos wool, it can be said that in some cases we can see

### Table 4. Contain asbestos minerals and other minerals in the decomposed material.

| Reagent              | Sample   | Other minerals          | Asbestos mineral |
|----------------------|----------|-------------------------|------------------|
| **Degreasing solution DS** | **Rope** | gypsum, talc             | no               |
|                      | **Wool** | gypsum, quartz           | cummingtonite     |
|                      | **Disc** | gypsum, anhydrite        | no               |
|                      | **Roof tile** | gypsum, quartz, rankinite | riebeckite       |
| **Sulfuric acid DS + H₂SO₄** | **Rope** | gypsum, talc             | chrysotile       |
|                      | **Wool** | quartz                  | cummingtonite     |
|                      | **Disc** |                         |                  |
|                      | **Roof tile** | gypsum, anhydrite, quartz | no               |
| **Phosphoric acid DS + H₃PO₄** | **Rope** |                         |                  |
|                      | **Wool** | quartz                  | cummingtonite     |
|                      | **Disc** | gypsum, talc             | no               |
|                      | **Roof tile** | gypsum, quartz, clinoclore | no              |
| **Hydrochloric acid DS + HCl** | **Rope** | talc, clinoclore         | no               |
|                      | **Wool** | quartz                  | cummingtonite     |
|                      | **Disc** | quartz                  | chrysotile       |
|                      | **Roof tile** | gypsum, quartz, clinoclore | no              |
| **Nitric acid DS + HNO₃** | **Rope** | talc                    | chrysotile       |
|                      | **Wool** | quartz                  | cummingtonite     |
|                      | **Disc** | quartz                  | no               |
|                      | **Roof tile** | gypsum, quartz           | riebeckite       |
complete decomposition of the fibres. The asbestos disc sample shows strong disruption of the surface and an absence of long fibres. In the case of the samples of asbestos roofing, there was a change of colour, swelling and partial disruption of the surface. In some experiments, there was a crystalline substance forming on the surface of the roofing. In the first series of experiments, the most suitable agent for the decomposition of asbestos rope is the mixture of ES and nitric acid, where the mass decrease was 80.8%. For comparison, in the second round of experiments, the highest mass decrease for the same sample was 41.3% in the case of the mixture of DS and phosphoric acid. The most suitable agent for asbestos wool was the mixture of ES with sulphuric acid and nitric acid, where both mixtures reached a mass decrease of 95%. In the second series, the highest mass decrease was noted with mixture of DS and phosphoric acid, which reached 62.1%. In the first series of experiments, the most suitable candidate for decomposition of the asbestos disc is the mixture of ES and sulphuric acid with the mass decrease of 100%. The best candidate from the second round was the mixture of DS and hydrochloric acid with the mass decrease of 72.7%. Concerning the asbestos roofing sample, the best result was a mass decrease of 86.7% with the mixture of ES and nitric acid. In the second series, the most effective mixture was the one of DS and hydrochloric acid with the mass decrease of 49.9%.

Table 5. Comparison of degradation efficiency.

| Sample       | Reagent        | Mass after decomposition [%] |
|--------------|----------------|------------------------------|
|              | \(H_2SO_4\)    | -56.1                        |
|              | \(H_3PO_4\)    | -132.7                       |
|              | HCl            | 42.4                         |
| Rope         | \(ES + H_2SO_4\)| 79.4                         |
|              | \(ES + H_3PO_4\)| 19.4                         |
|              | \(ES + HCl\)   | 73.3                         |
|              | \(DS + H_2SO_4\)| 31.3                         |
|              | \(DS + H_3PO_4\)| 41.3                         |
|              | \(DS + HCl\)   | 34                           |
|              | \(H_2SO_4\)    | -4.3                         |
|              | \(H_3PO_4\)    | 12.9                         |
|              | HCl            | 62.4                         |
| Roof tile    | \(ES + H_2SO_4\)| -49.7                        |
|              | \(ES + H_3PO_4\)| -3.2                         |
|              | \(ES + HCl\)   | 48.5                         |
|              | \(DS + H_2SO_4\)| 16.4                         |
|              | \(DS + H_3PO_4\)| -66.3                        |
|              | \(DS + HCl\)   | 49.9                         |

In an overall comparison of the decomposition results of all the materials used, ES is a more effective decomposing agent than DS. Also, the XRD results show that the decomposing agent ES is more effective in decomposing asbestos minerals than the agent DS.

The work [13] studied the decomposition of asbestos rope and asbestos roof tile by acids. For comparison with the results of this work, the critical decompositions of the two materials in sulfuric acid, phosphoric acid and hydrochloric acid. For a sample of asbestos rope, a mixture of acids and used waste solutions of ES and DS is more effective than pure acids. In the case of asbestos roof tile, on the other hand, pure acids achieve greater decomposition efficiency. Table 5 shows the comparison of results.
4. Conclusion
This work aimed to study the chemical decomposition of asbestos waste using industrial waste with the content of fluorides and residues of hydrofluoric acid in laboratory conditions. Industrial wastes used in the experiments were glassworking etching solution (ES) and metallurgic degreasing solution (DS). Sulphuric, phosphoric, hydrochloric and nitric supporting acids were used for the decomposition. The results show that the etching solution and its mixtures with acids are better decomposing agents than the degreasing solution and its mixtures. A different decomposing mixture is more suitable for each type of material. The results of the XRD analysis of the decomposed samples confirm the better degradation efficiency of the ES reagent. The research will continue with the improvement of already tested decomposition agents and with new suitable waste solutions for the decomposition of asbestos materials. Decomposition products, their safety and their use will be studied more.

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