

The Use of Basalt, Basalt Fibers and Modified Graphite for Nuclear Waste Repository - 12150

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ABSTRACT

New materials enhancing the isolation of radioactive waste and spent nuclear fuel are continuously being developed.. Our research suggests that basalt-based materials, including basalt roving chopped basalt fiber strands, basalt composite rebar and materials based on modified graphite, could be used for enhancing radioactive waste isolation during the storage and disposal phases and maintaining it during a significant portion of the post-closure phase.

INTRODUCTION

For further successful development of the nuclear energy sector there is a necessity to solve the related problem of safely storing and disposing of the accumulated nuclear waste. Finding such solutions that would be effective in a long term perspective requires extensive research and substantial financial support. Up to now, neither global science nor global technology has identified a solution that fully guarantees environmentally safe disposal of nuclear waste for sufficiently long periods of time when subjected to possible geological disasters or other environmental influences. At the moment, there are three basic strategies for the safe management and disposition of long-lived, highly-active, nuclear waste [1]:

1. Storage - This is the process of safely storing spent nuclear fuel in the spent fuel pools or in dry cask storages. This strategy implies that solutions for safe disposal of long-lived, highly-active, nuclear waste will be found in the near future.
2. Disposal - This is the process of once and for all disposing the nuclear waste. The currently globally-favored option is deep geological disposal in stable formations [2].
3. Transmutation - This is the process of converting by means of nuclear reactions most of the long half-life radioactive isotopes into non-radioactive isotopes or short half-life isotopes [3-5].

All three strategies require significant financial investments [6]. Especially “transmutation” requires long-term and high-cost researches before it could be used on commercial basis. At present, all countries using nuclear energy employ the first nuclear waste management strategy, whilst several but not all countries with long-lived, highly-active, nuclear waste are pursuing the second strategy and a few are pursuing the third strategy.

In any case, all of the abovementioned strategies require both the safe management and disposition of the generated long-lived, highly-radioactive, waste. Construction and operation of such systems is a challenging task because it requires materials that:

- A. Have a long-term resistance to radiation.
- B. Are reliable, strong and durable over a long period of time.
- C. Have the ability to withstand any emergency or extreme situation.

Based on the research and studies conducted by the authors, the construction materials described in the subsequent text meet the abovementioned three requirements.

BASALT

Whatever radioactive waste management strategy that is chosen, disposal of the long-lived nuclear waste in geological formations is an essential step in the nuclear waste management process even if the process of transmutation will be successfully developed. Therefore, a vast majority of ongoing R&D efforts focus on developing reliable processes for immobilizing the nuclear waste by means of its solidification (nuclear waste has to be converted into chemically and thermally stable forms suitable for transportation, storage and disposal). Successful solidification means creation of a protective matrix for the radionuclides that even when being exposed to air and water with considerable temperature fluctuations would be stable for hundreds and even thousands of years. Review of existing studies shows that manufacturing of such matrixes at present use two methods: 1) Vitrification; and 2) Ceramization [7, 8].

At present, vitrification is the only industrial-scale method that allows the conversion of nuclear waste to a relatively secure solid form. The vitrification method is extensively used in France, Britain, Russia, Germany, Japan and India [9]. However, research performed on nuclear fuel containing mass (which are actually glass-like materials) at the destroyed Unit 4 of the Chernobyl Nuclear Power Plant revealed that such fuel-mass tends to change its physical properties under the influence of radiation. On the macroscopic scale, lava-like fuel-contained mass (LFCM) are some glassy matrix of unknown atomic structure. Within 25 years after the Chernobyl accident it was getting obvious that such glass-like materials are actively deteriorated under internal self-irradiation. The study [10] shows that irradiated accidental fuel of "Shelter" and LFCM have the same important intrinsic property; their surfaces undergo spontaneous and continuous micro-degradation, even in the absence of any external influences. As a result, fractured fragments are highly dispersed in solid phase, which is referred to in technical practice as the "dust". The final stage of degradation of fuel containing masses is the transformation of lava-like fuel containing mass to submicron radioactive dust which already constitutes 90% of the inhaled dust for workers at the Chernobyl "Shelter" [11, 12].

The authors propose for immobilization of nuclear waste the basalt vitrification method as a good alternative to glass vitrification. Said method is very similar to the glass vitrification process but the nuclear waste melts in molten basaltic rocks. Physical and chemical characteristics of basalt exceed similar characteristics of glass materials and basalt is resistant to radiation. The uranium ore is mined from basaltic rocks and their joint long-term coexistence does not affect the properties of basalt deposits. For example, in Ukraine uranium deposits are

found in a region which consists mainly of basalt. This geological formation is known as the Ukrainian Crystalline Shield. Existing furnaces for vitrification can be retrofitted for melting basalt (such technologies are currently developed and implemented in the industry;) the authors conducted extensive research in this area).

BASALT ROVING

Regarding nuclear waste storages, it is necessary to point out that in most cases such waste is stored in metal or concrete protective containers which are placed in durable artificial or geological structures. The key condition of such arrangement is to ensure that the nuclear waste from the storage does not pollute air and groundwater. Nevertheless, during the long-term storage period there is significant probability that during an earthquake or during many other conceivable circumstances the integrity of the protective container can be destroyed and radioactive materials can reach and contaminate the surrounding environment. The authors propose the method of creating an elastic protection barrier around metal or concrete container made of continuous basalt roving. The correct construction of such barrier will significantly reduce probability of destruction of the protective containers and the cooling of radioactive material will be maintained at an acceptable level.

Basalt roving is a material made from extremely fine filaments of basalt, which is composed of the minerals plagioclase, pyroxene, and olivine (See fig. 1). It is similar to fiberglass but has better physical and mechanical properties than fiberglass for this particular application. In many applications basalt fibres are good a substitution even for carbon fibres, especially if the cost factor is an important issue. Basalt fibres are made from crushed basalt rocks from a carefully chosen quarry source and, unlike other materials such as fiberglass, essentially no other materials are added.



Fig. 1. Basalt roving.

The basalt fibres are known for their strength, corrosion and chemical resistance, thermal properties, moisture resistance; and dielectric nature. Some of the basic technical characteristics are presented in Table I.

Table I. Basalt continuous fibers technical characteristics.

Sustained operating temperature, (°C)	800
Minimum operating temperature, (°C)	-260
Melting temperature, (°C)	1450
Density, (g/cm ³)	2.8
Filament diameter, (microns)	13-20
Tensile strength, (MPa)	4200
Elastic modulus, (GPa)	89
Elongation at break, (%)	3.15
Sound absorption coefficient, (%)	0.9-0.99

At present, basalt fiber production plants are in operation in Ukraine, Russia, China and Austria. A similar industrial-scale facility is to be set up in Houston (Texas) in 2012.

CHOPPED BASALT FIBERS STRANDS AND BASALT COMPOSITE REBARS

The relevance of resistance to seismic activity of all nuclear power facilities, including nuclear waste repositories, is significantly increased after the accident at the Fukushima Power Plant. Construction of such facilities requires significant amount of concrete works and their strength is essential for the safe operation of Nuclear Power stations. Therefore, to increase the strength and lifetime of concretes, the authors propose to reinforce them with chopped basalt fiber strands and basalt fiber reinforced polymer (BFRP) rebars. Chopped basalt fiber strands are short pieces of basalt filaments that reinforcing binder mixtures, such as concrete (See fig. 2). Concrete reinforced with chopped basalt fiber strands has longer durability, high abrasion resistance, high shock resistance, high frost-resistance, high corrosion resistance, and high water resistance [13]. Another key advantage of basalt fibers is its low cost and its use will not much affect the construction cost of nuclear power facilities (table II). BFRP rebars are already used for the reinforcement of concrete structures (See fig. 3). Company HHK Technologies (USA) conducted considerable investigations in the field of production of basalt fibers and their applications in various industries (including nuclear energy).

Table II. The economic effect of using basalt fibers for dispersed concrete reinforcement in comparison to other fibers.

Type of fiber	Dosing of fiber per cubic meter of concrete, kg	Price for 1 kg of fiber, \$ (07-2011)	The cost of fiber per cubic meter of concrete, \$	Area, m ²	The cost of fiber for all area, \$
Polymer fiber (Poland)	3	6	18	100000	360000
Basalt fiber (Ukraine)	3	3.78	11.34	100000	227175
Copolymer fiber (USA)	3	16.25	48.75	100000	975000
Metal fiber	25	1.23	30.63	100000	612500



Fig. 2. Chopped basalt fiber strands.



Fig. 3. Basalt composite rebars.

MODIFIED GRAPHITE

Another material that can be used in the nuclear waste repositories is modified graphite and materials based on modified graphite (See fig. 4).

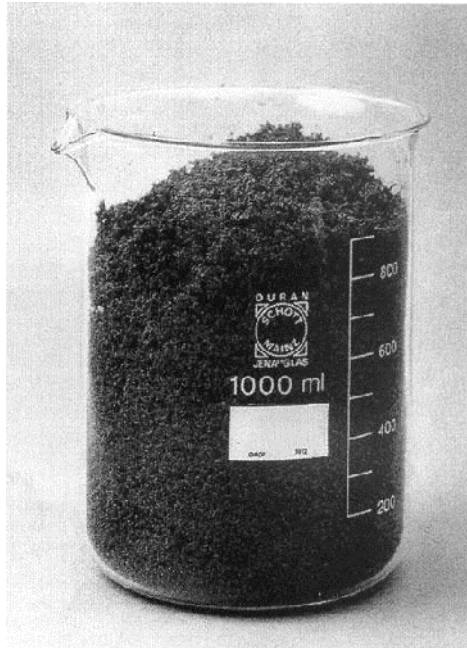


Fig. 4. Modified graphite.

New technologies allowed chemical modifications to the structure of graphite and to obtain completely new materials with surprising properties, which have revolutionized many fields of the construction industry and helped to solve many problems. Such materials are called modified graphite (MG).

Some basic characteristics of modified graphite are:

- Thermal resistance (graphite - the most refractory material in the world at 3700° C);
- Inertness (high resistance to radiation, chemical and biological aggression);
- Low friction coefficient ($K = 0.06$);
- Plasticity is not affected by either time, temperature or aggressive environments);
- Very good sorbent agent (1 g MG can absorb 80 g organophilic materials);
- Self-sealing ability in joints, junctions and cracks;
- Expansion ability - hundred times in volume when heated;
- Penetration ability into micro pores and capillaries of various materials (concrete, ceramics, metal, etc.);
- Impenetrable for gases and liquids; and
- Fire and heat insulating.

MGs also have unique waterproofing properties which is especially important in terms of preventing groundwater from reaching the radioactive waste. Materials based on MG also have the following advantages: fire resistance, corrosion resistance, high resistance to radioactive radiation, operating temperature range from -50 °C to +200 °C, resistance to chemical and biological aggression, resource use warranty is 30 years and up. Scientific-production enterprise GRAFPLAST (Ukraine) has developed a number of unique materials based on MG for use in

waterproofing of nuclear waste storages. The authors propose to use said materials for periodic improvement of waterproofing properties of nuclear waste repositories.

Materials based on MG are very well maintained in emergency and extreme situations. The waterproofing layer properties (made of MG) will remain intact even if basement cracks are up to 2 cm wide after earthquake impact. Open flame does not burn MGs. The MGs just expand, preventing fire to spread.

CONCLUSIONS

The basalt vitrification process of nuclear waste is a viable alternative to glass vitrification . Basalt roving, chopped basalt fiber strands and basalt composite rebars can significantly increase the strength and safety characteristics of nuclear waste and spent nuclear fuel storages.

Materials based on MG are optimal waterproofing materials for nuclear waste containers.

REFERENCES

1. Cometto M., Wydler P., Chawla R. A comparative physics study of alternative long-term strategies for closure of the nuclear fuel cycle / *Annals of Nuclear Energy*, 2004, Vol. 31, pp. 413–426.
2. Stahala M.P., Yim M., NcNelis D.N. Investigation of Yucca Mountain repository capacity for the US spent nuclear fuel inventory / *Annals of Nuclear Energy*, 2008, Vol. 35, pp. 1056–1067.
3. Kadi Y., Revol J.P. Design of an Accelerator-Driven System for the Destruction of Nuclear Waste: Proceeding // Workshop on Hybrid Nuclear Systems for Energy Production, Utilization of Actinides and Transmutation of Long-Lived Radioactive Waste. - Trieste, Italy: ICTP, 3-7 September 2001.
4. Bomko V.A. et al. The fast neutron incineration of nuclear waste in ADS – alternative of geological disposal for Ukraine // *Problems of atomic science and technology*. - 2004. - №4, Series: Plasma Electronics and New Methods of Acceleration. – pp. 43-50.
5. Chmelev A.N. et al. Nuclear Energy Systems: Safety, Transmutation of Radiowastes and Fuel Self-Sustaining // *Progress in Nuclear Energy*. - 1995. - Vol. 29. - P.439-443.
6. Accelerator-driven Systems (ADS) and Fast Reactors (FR) in Advanced Nuclear Fuel Cycles, A corporative Study, Nuclear Energy Agency, 2002.
7. Naline S., Gouyand F. et al. Vitrification 2010: A Challenging French Vitrification Project to Retrofit a Cold Crucible Inductive Melter at the LA Hague Plant // *WM2010 Conference: Final Proceedings*. - Phoenix, AZ, March 7-11, 2010.
8. Ringwood T. Immobilization of Radioactive Waste in Synroc / *American Scientist*, 1982, Vol. 70, N.2, - pp. 201–207.
9. Nuclear Energetics: Spent Fuel and Radioactive Waste Management // Ed by I.M. Neklyudov, Scientific book project, - Kiev, - Naukova dumka, - 2006, p. 253.
10. Zhidkov A.V. The fuel-containing materials of “Shelter” object today: Actual physical properties and capabilities for the prediction their state / *Problems of Chernobyl* / No 7, 2001, pp.23-40.

11. Baryakhtar V., Gonchar V., Kluchnikov A., Zhidkov A. Dust productivity of fuel-containing materials of “Shelter” object: experimental data, physical mechanisms, possible technology of prevention // Problems of Chernobyl / No 5, 1999, pp.63-64.
12. Gonchar V., Zhidkov A. The determining of the destruction mechanisms and important physical characteristics of irradiated fuel and LFCM of “Shelter” object // Problems of Chernobyl / No 4, 1999, pp.25-29.
13. Performance Evaluation of 3-D Basalt Fiber Reinforced Concrete & Basalt Rod Reinforced Concrete // Prepared by V. Ramakrishnan, S. Tolmare, V. Brik / Final Report for Highway IDEA Project 45, - South Dakota School of Mines & Technology, - Rapid City, SD – 1998.