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Study on hot melt pressure sensitive coil material for removing surface nuclear pollution dust

Jing Wang[1,2], Jiao Li[2], Jianhui Wang[1,2], Li Zheng[1], Jian Li[1] and Linmei Lv[1]

[1]Luoyang Hydraulic Engineering Technique Institute, Xishan Road, Luoyang, China

[2]Engineering Lab of Henan Province for Radioactive Decontamination Material and Equipment Technology, Wangcheng Street, Luoyang 471023, China

e-mail: jwang07@163.com

Abstract. A new method for removing surface nuclear pollution by using hot melt pressure sensitive membrane was presented. The hot melt pressure sensitive membrane was designed and prepared by screening hot melt pressure sensitive adhesive and substrate. The simulated decontamination test of the hot melt pressure sensitive membrane was performed by using 100 mesh and 20 mesh standard sieve dust for simulation of nuclear explosion fall ash and radioactive contaminated particles, respectively. It was found that the single decontamination rate of simulated fall ash and contaminated particles were both above 80% under pressure conditions of 25kPa or more at 140°C. And the maximum single decontamination rate was 92.5%. The influence of heating temperature and pressure on the decontamination rate of the membrane was investigated at the same time. The results showed that higher heating temperature could increase the decontamination rate by increasing the viscosity of the adhesive. When the adhesive amount of the adhesive layer reached saturation, a higher pressure could increase the single decontamination rate also.

1. Introduction

Nuclear radiation was a major threat to mankind in the process of nuclear energy development and utilization. With the occurrence of several catastrophic nuclear accidents, people paid more and more attention to the removal and management of nuclear pollution [1,2]. In the nuclear fuel extraction, processing, storage and transportation process, nuclear facility leakage accidents, nuclear terrorist attacks were both likely to produce different levels of nuclear pollution dust or particulate pollutants. The protection and removal of nuclear pollution was an important measure to ensure the safety of the environment and the public [3-5]. Scientists had proposed chemical decontamination, physical decontamination, electrochemical decontamination, biological decontamination and other nuclear pollution removal methods for the control and removal of radioactive dust. These methods have their advantages, disadvantages and scope of application [6-11]. The commonly used for the removal of radioactive dust was the strippable polymer membrane method [8,12,13]. However, the drying process and removal of the polymer membrane during the decontamination took a long time and greatly reduced the timeliness of the pollution removal [14]. In order to realize the rapid removal of nuclear pollution dust, this paper presented a novel method for removing surface radioactive contamination quickly by using hot melt pressure sensitive coil material. The hot melt pressure sensitive coil was designed and prepared. And the simulated decontamination test was conducted by simulating nuclear dust.

2. Materials and Methods

2.1. Principles and methods of decontamination coil
The method of using strippable polymer membrane to remove nuclear pollution dust was through the infiltration, adsorption or chelating effect of dust into the membrane body. However, the conversion from liquid polymer to polymer membrane usually needs several hours. In order to shorten the time of decontamination, a novel idea of using hot melt adhesive to stick and adsorb pollution dust is developed. In this technical solution, the hot melt adhesive is heated and melted to infiltrate and adsorb dust. After cooling, the pollution dust is embedded and cured by the hot melt pressure sensitive coil. Then, remove the coil to achieve the purpose of decontamination.

A hot melt adhesive layer was designed on the surface of the substrate, preformed into a continuous nuclear contamination removal material, and the material was wrapped in a viscose tape in the form of a decontamination tape. When using the decontamination coil material for nuclear pollution removal operations, a special web laying machine was used to coat the decontamination coil material onto the contaminated surface. The decontamination coil material was heated when coating, so that the hot melt adhesive layer was melted to obtain viscous force, and then the decontamination coil material was pressed against the contaminated surface with an appropriate pressure. The hot melt adhesive conglutinated or wrapped nuclear pollution dust and particles, with cooling and curing, then a rewinding machine was used to remove the decontamination coil material which containing pollution dust and particles, the complete nuclear pollution clearance operation was completed.

2.2. Material design and selection
The decontamination coil material is mainly composed of hot melt adhesive layer, substrate and anti-sticking treatment layer. The schematic diagram of the coil material is shown figure 1. The hot melt adhesive layer is the fundamental functional unit that provides adhesion. The substrate is the principal structural unit that provides the required mechanical strength for the coil material to meet the laying and winding operations. The anti-sticking treatment layer is an important auxiliary unit, and it is possible to prevent the adjacent two-layer hot-melt adhesives and the substrates from sticking to each other, thereby making it difficult to roll out.

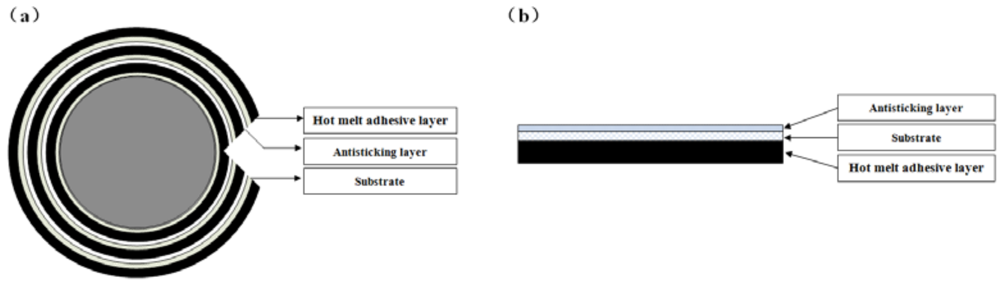

Figure 1. Schematic diagram of decontamination coil (a: winding state; b: single-layer).

There are two basic requirements for hot melt adhesive material. First, alternative material has low viscosity and it is not easy to deformation at room temperature, which maintain the stability of the adhesive layer. The other one, when the temperature increases, the viscosity of the material become larger and it is sensitive to pressure, which can be softened and deformed to adhesion and wrapped particulate pollutants better. Hot melt pressure sensitive adhesive (HMPS) can better meet the above requirements. HMPS is a thermoplastic polymer-based adhesive, and it has the dual characteristics of hot melt and pressure sensitive. Depending on the temperature of use, HPMS is divided into two types: traditional type (160-180℃) and low temperature type (≤140℃) [15]. In this paper, low temperature type (HMPS-I) and traditional type (HMPS-II) adhesives were selected for coating experiments. By comparing their softening temperature, melt viscosity and cooling conditions after coating to choose a better adhesive. The test results are shown in table 1. Although both the melt viscosity did not affect the coating requirements, HMPS-IIwas hard and brittle after costing, so low temperature type was chosen the adhesive.

Table 1. Properties of different HMPSs.

Type of HMPS	Softening temperature (℃)	Temperature of melting (℃)	Viscosity of melting (mPa·s)
HMPS-Ⅰ	110	145	1000
HMPS-Ⅱ	160	190	1100

There are three basic requirements for substrate. First, the alternative substrate has a sufficient tensile strength to ensure that the process of coil material laying and reeling is not easy to be torn. Second, the maximum using temperature is higher than the melting temperature, to ensure that the melt coating the substrate is not damaged during coating. The last one, the bonding strength of the adhesive surface and hot melt adhesive is high enough, and the back surface of the adhesive is easy to be anti-sticking treatment. In this paper, the silicon fabric was selected as the substrate, and silicone rubber was compounded on the back surface of the adhesive as anti-sticking layer. Its performance parameters are shown in table 2.

Table2. Performance parameters of the silicon fabric.

Performance	Tearing strength ($kN\cdot m^{-1}$)	Tolerable temperature (℃)	Areal density ($g\cdot m^{-2}$)
Parameter	30	230	300

2.3. Preparation of coil material

The hot melt pressure sensitive coil material was prepared using the selected hot melt adhesive material and substrate. The preparation process was as showed in figure 2. The silicone rubber anti-stick layer thickness was controlled at 0.1mm, the hot melt adhesive layer was controlled at 1-3mm, the coating temperature was 140 °C, ventilated cooling of the material. Figure 3 showed the decontamination coil material sample having a width of 1.2 m and a layer thickness of 1mm.

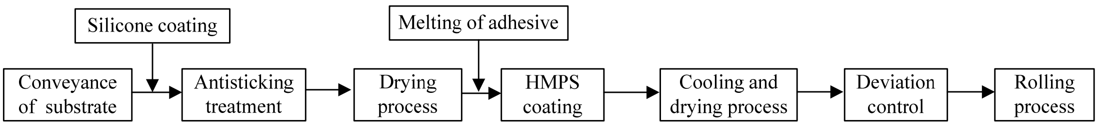

Figure 2. Preparation processes of decontamination coil.

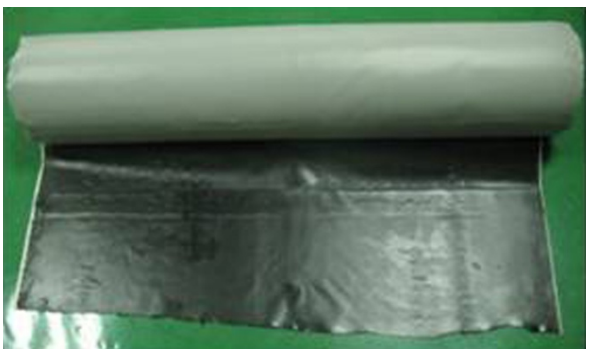

Figure 3. Display of the coil material sample.

2.4. Decontamination test of coil material

Dust and sand were used to simulate radioactive dust in the detergency tests. Dust over 100 mesh (size 0.15mm) sieve was used to simulate nuclear explosion fall ash, dust over 20 mesh (size 0.85mm) sieve was used to simulate particle pollution. The mass of m_1 simulated dust was evenly sprinkled on the stainless steel test bed, the decontamination coil material was covered on dust after the temperature and pressure were imposed, the remaining dust mass m_2 was weighed after the decontamination coil material was lifted, the simulated dust removal rate η could be calculated according to equation (1).

$$\eta = \frac{m_1 - m_2}{m_1} \times 100\% \tag{1}$$

3. Results and discussion

3.1. Effect of heating temperature on decontamination rate of the coil material

Two different particle size dusts were used to perform decontamination tests at different temperatures between 110~140℃. The results of the single decontamination rate were shown in figure 4.

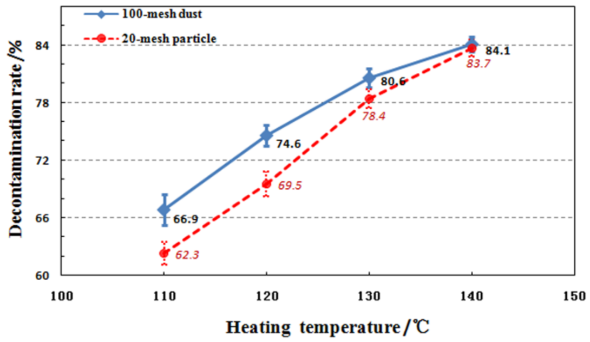

Figure 4. The decontamination rate of the coil at different heating temperatures.

As can be observed in figure 4, the single decontamination rate of 100-mesh dust was 66.9~84.1%, and the single decontamination rate of 20-mesh particles was 62.3~87.2%. Experimental results showed that the decontamination rate increased with the temperature increasing. Hot melt adhesive layer began to soften at 110℃, when the temperature gradually increased, the hot melt adhesive layer gradually became sticky, so the single decontamination rate of the two pollutants gradually increased. When the temperature was low, the hot melt adhesive layer began to soften and the adhesion was not strong, so the decontamination effect on smaller particles was stronger than bigger particles. When the temperature was close to the melting temperature of the adhesive layer, the adhesion became stronger, and this gap was gradually reduced.

3.2. Effect of pressure on decontamination rate of the coil material

Two different particle size dusts were used to perform decontamination tests under different pressure between10~30kPa at 140℃. The results of the single decontamination rate were shown in figure 5.

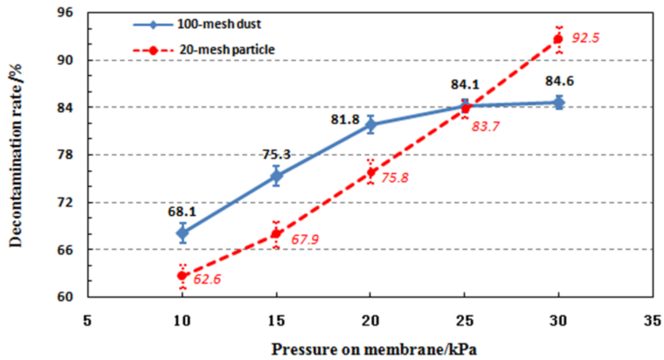

Figure 5. Decontamination rate of coil under different pressures.

The single decontamination rate of 100-mesh dust was 68.1~84.6%, and the single decontamination rate of 20-mesh particles was 62.6~92.5%. Experimental results showed that the decontamination rate increased with the pressure increasing. The slope of the single decontamination rate of 100-mesh dust decreased, decontamination rate increased a little when the pressure was bigger than 25kPa. Slope of the single decontamination rate of 20-mesh dust basically remain unchanged. That is to say, the decontamination efficiency of 20-mesh dust roughly linearly increased. The reason for this phenomenon may be that the specific surface area of 100-mesh dust was greater than 20-mesh particles, so the adhesion of the hot melt adhesive layer to 100-mesh dust was saturated earlier and the removal rate was no longer increased.

4. Conclusions

In this paper, a method to remove nuclear pollution dust and particles by hot melt pressure sensitive adhesive was proposed. The hot melt pressure sensitive decontamination coil material was designed, prepared and optimized, and can be used to remove nuclear pollution on flat surface. The simulated dust was subjected to decontamination test, and the influence of heating temperature and pressure on the single decontamination rate of the adhesive were explored. The specific conclusions were as follows.

(1) Increasing the temperature of the adhesive layer could enhance the adhesive force of the adhesive layer, thus increasing the single decontamination rate of the hot melt pressure sensitive membrane.

(2) Before the adhesive amount of dust in the adhesive layer was saturated, increasing the compressive strength could increase the single decontamination rate of the hot melt pressure sensitive membrane.

(3) When the temperature was 140 ℃, and the pressure was greater than 25kPa, the single decontamination rate of the hot melt pressure sensitive membrane on both simulated dust and particulate pollutants were greater than 80%. The highest single decontamination rate reached 92.5% at 140 ℃, 30kPa. It is proved that the hot melt pressure sensitive decontamination coil material was a good surface nuclear pollution removal material.

Acknowledgements

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