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Development of nuclear emulsion detector for muon radiography

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Abstract

Muon radiography is the non-destructive testing technique of large-scale constructions with cosmic ray muon. Cosmic ray muon has high penetrating power and it always comes from the whole sky. In the same way of taking a X-ray photograph, we can obtain integrated density of constructions which thickness are several tens to several hundreds. We had ever applied this technique to nuclear reactors, volcanos, and so on. Nuclear emulsion is three dimensional track detector with micrometric position accuracy. Thanks to high position resolution, Nuclear emulsion has mrad angular resolution. In addition, the features which require no power supply and can observe in a large area suitable for muon radiography. In Nagoya University, we launched emulsion manufacturing equipment at 2010. It has become possible to flexible development of our detector and succeeded to development of high sensitive nuclear emulsion film (Nagoya emulsion). An important factor is the temperature characteristic to withstand the outdoor observation as a detector to be used in the muon radiography. There is a phenomenon of a latent image fading, whichit is well known in the photographic industry, and this phenomenon is known that temperature and water are involved. So we examined temperature and humidity characteristic of latent image fading about Nagoya emulsion. As a result, we found latent image fading is strongly depends on both temperature and humidity. By dehydrating emulsion film in RH8%, over 95% (Grain Density>40) detection efficiency of muon track keeps over 3months in 25degree, for 2months in 35degree. Additionally it was showed in this test that increasing back ground noise “fog”, which may have occurred by sealing emulsion film in a narrow space, is reduced by buffer space in the bag.

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Keywords: Muon radiography, Cosmic ray muon, Nuclear emulsion, Fading latent image

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1. Introduction

1.1. Muon radiography

Muon radiography is non-destructive testing technique of large structures. Cosmic ray muons comes from sky and go thorough matters. The muon transmission rate is decided by how much there is the matter on the pass of muon. Like X ray radiography, we can know the matter density by muon. In 1967, the first demonstration "Perspective of the pyramid" was done by W.Alvarez (Luis et al. 1970). In 2006, H.Tanaka and T.Nakano observed Mt.Asama which is active volcano, and succeeded in perspective (Tanaka, 2007). They used nuclear emulsion detector with high speed automated scanning system "S-UTS" (Morishima and Nakano, 2010) for this observation.

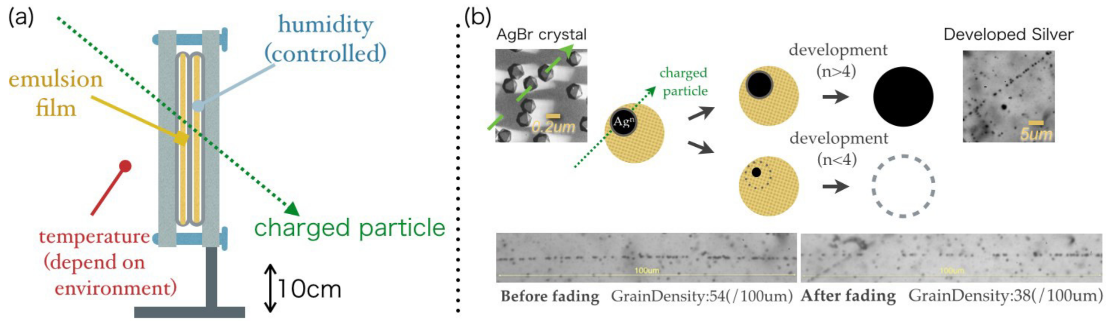
1.2. Nuclear emulsion detector

To accurately perspective the larger objects, it is necessary to detect more large statistics. Because of the flax of cosmic ray muon is constant, it is necessary to enlarge detector area or extend observation time. Because nuclear emulsion film is compact, inexpensive and no need electric power, it is easily possible to do observation with large area nuclear emulsion detector. Also we installed emulsion manufacturing equipment in Nagoya University to develop emulsion manufacturing technique, and succeeded to development of high sensitive nuclear emulsion film by increasing the occupancy of AgBr crystals (Nagoya emulsion).

1.3. Fading latent image

In order to carry out long-term observation by nuclear emulsion, it is necessary to know the long-term performance of the detector. There is a phenomenon of a latent image fading, which is well known in the photographic industry, but this is no exception in the nuclear emulsion film. Fig 1 (a) shows structure of nuclear emulsion detector. Fig 1 (b) shows measurement principle of nuclear emulsion detector and how to proceed the fading phenomenon. According to the paper of Y.Kozeki, fading latent image is understood by chemical reaction formula (1). We examined temperature and humidity characteristic of latent image fading about Nagoya emulsion.

$$2Ag + 4H_2O + O_2 \Leftrightarrow 2Ag^+ + 4OH^- \quad (1)$$



n : The number of silver atoms that constitute the latent image

Fig 1 (a) This figure shows structure of nuclear emulsion detector in cosmic ray muon radiography. We can control and keep humidity of emulsion film in the observation by using aluminum laminate bag. Temperature is uncontrollable in general. (b)This figure explains measurement principle of nuclear emulsion detector and how to proceed the fading phenomenon.

2. Temperature and humidity characteristic

In general, chemical reaction is accelerated in high temperature. And the reaction rate is related to humidity because fading is oxidation of silver. In this experiment, we used Nagoya emulsion, the crystal size is 200nm, volume ratio of AgBr and gelatin is 55:45, and cut it 2cm square size, thickness of emulsion layer is 50μm. In constant-temperature and humidity bath, each sample is controlled humidity to RH8%, 20%, 50% for 4hours. After humidity conditioning, the samples are put in aluminum laminate bag and sealed with heat sealer. In a moment, remove air with vacuum pump. And then, expose tens to hundreds MeV electron beam in UVSOR(Okazaki,Aichi). Bring its back to Nagoya University and put it in 25 or 35degrees constant-temperature bath or outdoor which average temperature 8degrees. Put it out in 0, 7, 14, 31days later after conditioning started, chemical development was performed soon. After that, we evaluated Grain Density (GD) and Fog Density (FD) by using optical microscope. GD is defined as the number of grain on the 100μm track and FD is the number of background grain in 10μm cubic. 8degree condition is only RH50%, and until 14day. RH8% condition is prepared samples in also 57, 83days. Fig 2 (a) (b) (c) shows latent image fading characteristic in each temperature.

We found fading latent image characteristics is strongly depends on both temperature and humidity as shown in Fig 2 Reed out efficiency of muon track by S-UTS keeps over 95% in GD>40, so in practical, nuclear emulsion film that dehydrate under RH8% is available for more 3months in 25degree. But it should be noted that Fog Density which shows bag ground noise level gradually increasing in RH8%.This phenomenon is more accelerated in 35degree, so unevaluated GD in RH8%. In this condition, we can't use emulsion detector for muon radiography. We decide to call this phenomenon "Black effect" and examined in more detail about this.

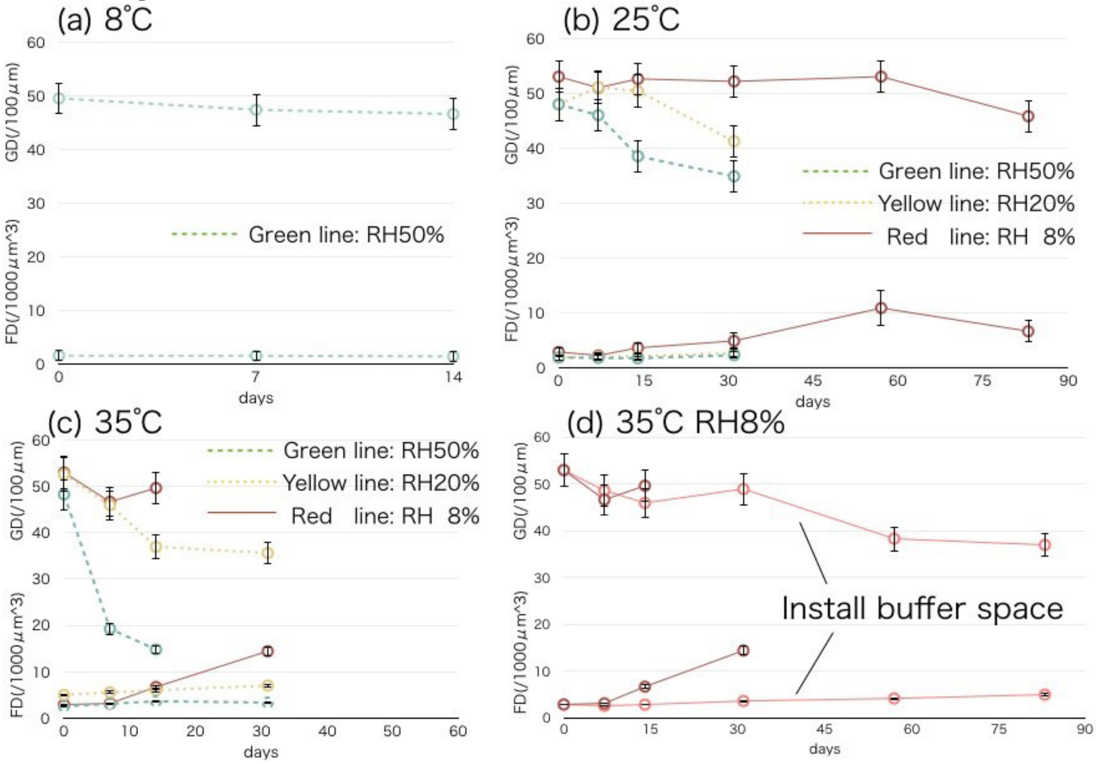


Fig 2 This figure shows temperature and humidity characteristic of Nagoya emulsion. Humidity condition is below : red:RH8% yellow:RH20% green:RH50%. Temperature condition is below : (a) 8degree (b) 25degree (c) 35degree. In the case of conditioning high temperature and low humidity, the BG noise "fog" increase and unevaluated GD (d) Comparison of installing small buffer space in the bag or not installing. Installing small buffer space in the bag help suppressing FD.

4. Black effect

In OPERA experiment (Nakamura et al. 2006), it had been known that FD gradually increase up to 10 in the environment of 15degree RH60% in 200days with the films in the bags removed air. FD over 10 was too high back ground noise to analysis. In this time, make small hole in the bags, and let in air. By this way, increasing FD was stopped. From this result, we estimated "Black effect" accelerate by same mechanism of this phenomenon at high temperature. But we can't make a hall because have to control humidity to control fading latent image phenomenon, so we introduced buffer space in the bag and research the effect.

We did this test as the same time as the test of section 2. We prepared a sample which humidity controlled RH8% and packed with RH8% air as buffer space. Introduced buffer size is about 100cc. We compared this condition with before test's result "Fig 2 (c) RH8%". Stored the samples in 35degree constant-temperature bath and put it out 0, 7, 14, 31, 54, 83days later. Fig 2 (d) shows the result comparing buffer space introduced sample with no buffer space sample. We see from this figure the buffer space help suppressing FD, and we got a conclusion that detection efficiency of muon track keeps over 95% (GD>40) for more 2months in 35degree.

5. Conclusion

The result of our experiment shows the characteristic of latent image fading about Nagoya nuclear emulsion. There is significant difference by temperature and humidity, and dehydrate in RH8%, over 95% (GD>40) detection efficiency of muon track keeps over 3months in 25degree, for 2months in 35degree. Additionally it was showed in this test that increasing back ground noise "fog", which may have occurred by sealing emulsion film in a narrow space, is reduced by buffer space in the bag.

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