(REFEREED RESEARCH)

# STUDY OF MECHANICAL PROPERTIES FOR FILTER BAG MATERIALS UNDER THERMAL SHOCK

# ISIL ŞOK ALTINDA, FİLİTRE TORBASI MALZEME/KUMAŞLARININ MEKANİK ÖZELLİKLERİNİN İNCELENMESİ

**Jianliang HE, Henggen SHEN***

*College of Environmental Science and Engineering, Donghua University, Shanghai, 2999 North Renmin Road, Shanghai 201620, China*

Received: 02.12.2015 Accepted: 24.08. 2016

**ABSTRACT**

In this work, we present a novel facility and method for the measurement of mechanical properties of filter bag materials under thermal shock with pre-tensile loading. In contrast to most current test equipments, the new facility is not only able to provide constant cyclic thermal shock but also test tensile strength under high temperature at the same time. It reflects the real mechanical properties under high temperature after thermal shock with tensile loading. It discovers that thermal shock accelerates degradation of the mechanical properties of the filter bag materials. The effect of cyclical thermal shock on the filter bag materials microstructure is investigated by scanning electron microscope (SEM), X-ray diffraction (XRD) and dynamic mechanical analysis (DMA). It is found that the crystallinity of filter bag materials increases with increasing of thermal shock cycles. It is concluded that the thermal shock effects on crystallinity and microstructure of filter bag materials.

**Keywords:** Filter bag materials, Thermal shock, Measurement, Mechanical properties, Mechanism

**ÖZET**

Bu çalışmada, ön gerilimli yükleme ile ısıl şok altında filtre torbası malzemelerinin mekanik özelliklerinin ölçümü için yeni bir tesis ve yöntem sunmaktayız. En güncel test cihazlarının aksine, yeni tesis ve yöntem sadece sabit periyodik ısıl şok sunabilmekte kalmadığı gibi, aynı zamanda yüksek sıcaklık altında, gerilme kuvvetini de test edebilmektedir. Gerilme yüklemeli ısıl şoktan sonra, gerçek mekanik özellikleri ortaya çıkarır. Isıl şok'un filitre torbası malzemelerinin mekanik özelliklerinin bozulmasını hızlandırdıgını keşfeder. Periyodik ısıl şokun filtre torbası malzemelerinin mikroyapısına etkisi, taramalı elektron mikroskopu (SEM), X-ışını kırınımı (XRD) ve dinamik mekanik analiz (DMA) ile araştırılmıştır. Filitre torbası malzemelerinin kristalinitesinin (kristalleşme derecelerinin), artan ısıl şok periyodları ile arttığı bulunmuştur. Isıl şokun, filtre torbası malzemelerinin kristalinitesi (kristalleşme derecesi) ve mikro yapısı üzerinde etkisi olduğu sonucuna varılmıştır.

**Anahtar Kelimeler:** Filitre torbası malzemeleri, Isıl şok, Ölçme, Mekanik özellikler, Mekanizma

**Corresponding Author:** Henggen Shen, riverss1978@hotmail.com

## 1. Introduction

Filter bags are important materials for purification process of gas in industry, providing high filter efficiency and adaptability under a broad variety of working conditions [1, 2]. Although part of filter bags are made of polyester nonwoven for the low-cost, the application of them is limited by the factor that polyester filter bags exhibit short service life [3, 4]. Thus, the reasons causing short life of polyester filter bags are studied. A commonly used method is mechanical properties testing, which is often carried out by testing tensile strength of filter bag materials after being subjected to the thermal load under room temperature without pre-tensile loading[5,6]. It neglects the role of complex loading conditions including thermal and mechanical loads. These results in that the relationship of high-temperature exposure to service life of filter bag materials during the complex working condition is not been discovered.

In order to understand characteristics of filter bag materials to thermal exposure and shock with mechanical loads, it is necessary to design and develop a novel test method for studying the materials properties under complex thermal

and mechanical loading condition. However, the most methods for characterization of the mechanical properties of filter bag were just carried out on a high-temperature exposure and then cooling down for testing the tensile strength. It was not only missing some important information but also reflecting false performance. Thus, the researchers have not found the relationship between mechanical properties of filter bag and thermal shock. Moreover, there is almost no research about mechanism of mechanical properties variation of filter bag under thermal shock. It is a challenge to incorporated real working condition including thermal shock, high temperature and tensile loading into measurement.

Recently we have developed a new facility and method for testing the mechanical properties of filter bag under simultaneous complex condition. In contrast to most current test equipments, the new facility is not only able to provide constant cyclic thermal shock but also test tensile strength under high temperature at the same time. It can avoid the problem arising for testing the tensile strength of specimen after re-cooling, which can reflect the real mechanical properties under high temperature after thermal shock with tensile loading. In this study, mechanical properties were characterized by using the new facility, which found thermal shock has great effects on the mechanical properties of the filter bag materials. Furthermore, we investigated the mechanism of mechanical property variation causing by thermal shock by scanning electron microscope (SEM), X-ray diffraction (XRD) and dynamic mechanical analysis (DMA).

## 2. Description of novel test facility

The current methods for the characterization of the tensile strength of filter bag materials under thermal shock are not directly, which are measured through pre-heating in oven and subsequently re-cooling for testing its tensile strength by fabric strength tester. However, results are provided in such method are not able to indicate the real properties of filter bag materials which suffered on constant thermal shock and weight load.

A novel test facility can simulate actual working condition and measure mechanical properties synchronously for filter bag materials was developed. The tensile strength test of filter bag materials can be carried out both under constant thermal shock with pre-tensile loading by new facility, which is able to directly measure and reflect real mechanical properties. A standard tensile testing machine used for tensile tests was modified and adapted to the new concept (Figure 1). The new facility used in the proposed method including heating and cooling system, clamping and tensile devices, sensor and computer control system. A seal chamber is composed of air heater, air-cooling and induction, which can be simulated the thermal shock condition and controlled precisely.

The temperature control systems control temperature within the range of ambient to 200 ℃ at heating or cooling rate of about 0.5~5℃/s, and stability control to the temperature volatility within 2 ℃.

It offers a quick, flexible and reproducible option where the pre-heating and subsequent cooling times could be avoided during determining its tensile strength.

## 3. Experiment

### 3.1 Materials

Filter bag materials of polyester non-woven fabric with 2.2 Dtex fineness had 1.55 mm thickness and density at 450 g/m$^2$. All samples were cut into 25.0×5.0 cm and placed in constant temperature and humidity air conditioning (20±2℃, relative humidity:65±2 %) in textile laboratory for 24 h before the test.

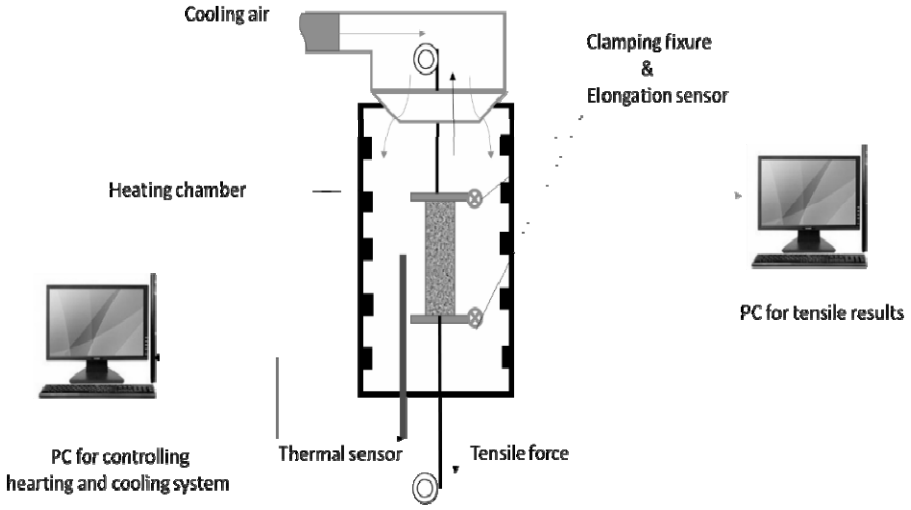


**Fig. 1.** The scheme of novel test facility

### 3.2 Characterization

***Tensile strength test.*** Tensile strength of filter bag materials under thermal shock or un-shock with pre-tensile were tested by novel or regular method. The polyester filter bags operate at temperatures of 90 ℃ ~ 100 ℃, and they suffer to periodic thermal shock at between 130℃ and 150 ℃ due to the heat source fluctuation during the working process. In the process of the working condition, the filter bags subject to not only their own gravity but also the weight of adsorbing dust layer. Thus, the specimen filter bag materials by novel test facility was clamped under pre-tensile at 63.5 N according to the calculation in the seal heat chamber vertically with clip distance at length of 250 mm and width of 50 mm. The temperature of chamber was up to a continuous working temperature(100 ℃) and held for 24 min. Afterwards, heating up of chamber to transient thermal shock temperature (150 ℃) with the heating rate of about 5 ℃/ s and keep the temperature of chamber for 6 min. After then, the chamber was cooled down to 100 ℃ with the cooling rate of about 5 ℃/ s. This progress as one thermal shock cycle for simulating a desired thermal shock temperature of filter bag materials during the real working conditions. Subsequently, the tensile strength of specimen under working temperature after target thermal shock cycle was measured immediately and the results data were collected and displayed on the computer.

***Scanning electron microscope (SEM).*** The morphology of samples before and after thermal shock were observed on the scanning electron microscope (HITACHI S4700 ).

***X-ray diffraction (XRD).*** X-ray diffraction (RIGAKU D/max-2550 PC) patterns were determined for crystallinity with an area detector operating under 40 kV and 200mA, using Cu Kα radiation (λ =0.1542 nm).

***Dynamic mechanical analysis (DMA).*** The dynamic mechanical behavior of the specimens was determined using a dynamic mechanical analyzer (TA instrument DMA Q800) in tensile mode at 1 Hz and a heating rate of 1 ℃/min in the temperature range of 25 to 200 ℃. Storage modulus(*E'*) and tan delta(*tan δ*) values of specimens were observed. The samples were prepared by cutting 4 mm wide strips from the original sample.

## 4. Results and discussion

### 4.1 Residual tensile strength

The mechanical properties change of filter bag materials causing by the thermal chock cycles was determined after the samples under un-shock or thermal shock with pre-tensile loading for 12 cycles. The results of the residual tensile strength of filter bag materials are presented in Fig. 2. It can be seen that the residual tensile strength measuring by novel method of samples un-shock for each equal cycle time was almost no change. In contrast, the residual tensile strength of samples for each cycle under thermal shock change obviously whatever the test method was novel or regular. Moreover, the variation trend of residual tensile strength for both of them was increased first and then decreased. It indicates that thermal shock has great effects on the mechanical properties of the filter bag materials. However, compared to residual tensile strength change range and rate of samples for each cycle measured by regular method, the change of samples measured by novel method was greater and faster. This is most probably due to the novel test method keeps a constant thermal load, which avoids molecular rearrangements as a result of re-solidification causing by cooling. Therefore, the novel method is able to reflect real condition of sample after constant and cyclical thermal shock much more truthfully.

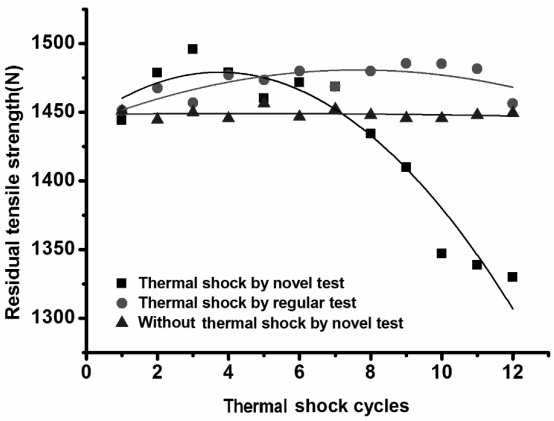


**Fig. 2.** Residual tensile strength of filter bag materials with pre-tensile loading under un-shock and thermal shock in dependence on the temperature.

### 4.2 Morphology

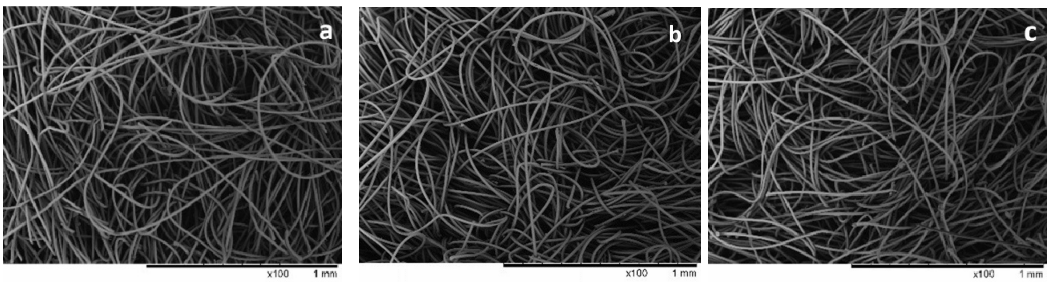


Fig. 3 SEM micrographs of filter bag materials before and after thermal shock with pre-tensile loading. (a. before thermal shock; b. thermal shock after 6 cycles; c. thermal shock after 12 cycles)

The mechanical properties of filter bag materials are mainly affected by the properties of the fibers and fabric [7]. Fig. 3 shows the surface morphologies of filter bag materials before and after thermal shock with pre-tensile loading. As compared with the morphology of the bag materials before thermal shock (Fig. 3a), there was almost no change in the fiber debonding, breakage and fineness in the bag materials after 6 and 12 cycles of thermal shock with pre-tensile loading (Fig. 3b and 3c). However, it is found that the residual tensile strength of the bag materials after thermal shock with pre-tensile loading exhibited significantly changes by our novel test method. Thus, we speculate that the mechanical properties change of filter bag materials after thermal shock with pre-tensile loading may be caused by the changing of microstructure of fibers in filter bag materials.

### 4.3 Crystallinity

X-ray powder diffraction (XRD) represents the most frequently used method for the revelation of the micro-structural of the sample. It was employed to verify the micro-structure change of filter bag materials after thermal shock tests. The XRD patterns and crystallinity are shown in Fig. 4a and 4b, respectively. The XRD patterns of the samples under un-shock and thermal shock with pre-tensile loading by our new method in Fig. 4a shows the characteristic peaks of polyester at about the $2\theta$ of 17.48, 22.53 and 25.88°, which corresponds to the (010), (110) and (100) crystal planes, respectively [8,9]. Filter bag materials without thermal shock did not exhibit peak area and shape changes, as shown in Fig. 4a (left). In stark contrast, the peak area and shape of the filter bag materials under thermal shock with pre-tensile loading (Fig. 4a right) were increased clearly with the frequency of thermal shocking increasing, corresponding to crystallinity increasing. The crystallinity analysis in Fig. 4b shows that, the crystallinity of the filter bag materials under increasing the thermal shock number with pre-tensile loading were improved apparently, compared with the materials without thermal shock with pre-tensile loading. When the temperature of thermal shock is high enough, molecular chains in amorphous region of fiber would move and orientate with being pre-tensile loading, which are the main reason caused the crystallinity increase and microstructure change. As we know, the mechanical properties increase with increasing of crystallinity due to the increasing of intermolecular force [10]. The residual tensile strength increase with increasing of thermal shock cycles under pre-tensile loading, where the materials suffer to less than three cyclic thermal shock (in Fig. 2). However, the tensile strength of filter bag materials under thermal shock with pre-tensile loading decrease with the continual increasing of crystallinity higher than 58 % (Fig. 2). The reason of tensile strength loss during the thermal shock is most probably due to materials stiffness and brittleness increasing too much as the crystallinity increasing. The novel test facility measured the tensile strength of filter bag materials directly under a constant working temperature and successive thermal shock with pre-tensile loading. It avoids a pre-heated and subsequently pre-cooled test specimen for determining its tensile strength by most current methods. Hence, it is better able to reflect the real conditions where the actual behavior of the materials under the dramatic temperature fluctuations.

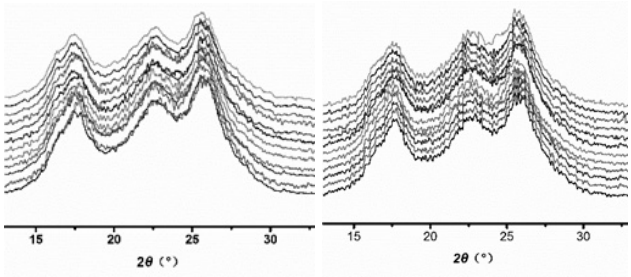


**Fig.4a** XRD patterns of filter bag materials with pre-tensile loading under un-shock (left) and thermal shock (right)

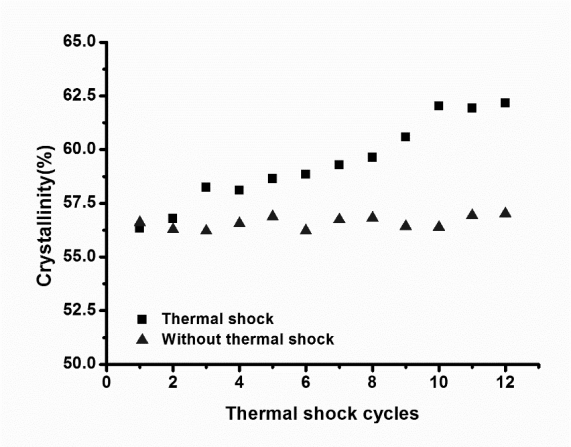


**Fig.4b.** Crystallinity of filter bag materials with pre-tensile loading under un-shock and thermal shock

### 4.4 DMA

Dynamic mechanical analysis was carried out in the tension mode for determining the characteristics of the polyester filter bag materials without thermal shock or under twelve cycles of thermal shock. The glass transition temperature $T_g$ is the temperature which corresponding the peak of *tan δ* in the glass transition region [11]. From Fig. 5a, it was 83 ℃ for the sample without thermal shock and 87 ℃ for the sample after twelve cycles of thermal shock. The $T_g$ of sample with thermal shock increased due to the enhancing the crosslinking density, corresponding to the results of XRD for crystallinity increasing. Storage modulus (*E'*) of polyester filter bag materials under thermal shock and un-shock are presented in Fig. 5b. It decreased with increasing temperature for both samples. The major decrement occurred at the glass transition region. After the glass transition region both of them began to crystallize and this resulted in the increase of *E'* of the samples at 110 ℃. As it can be seen from Fig. 5b, the filter bag materials after thermal shock increased the storage modulus (*E'*) when compared with the sample un-shock, due to the increasing crystallinity of sample after twelve cycles thermal shock [12]. This result is in accordance with the crystallinity calculated from XRD analysis.

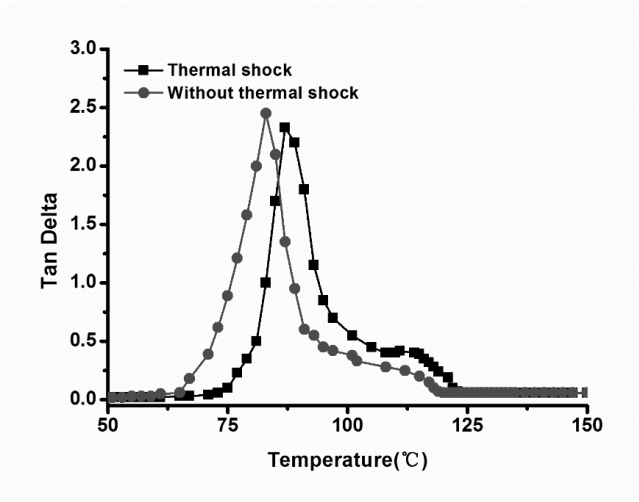


**Fig.5a.** Tan delta of samples with pre-tensile loading under un-shock and thermal shock (twelve cycles)

## 5. Conclusions

In this work we have presented a novel facility for the determination of tensile strength under thermal shock with pre-tensile loading. It was a novel and reliable measuring method with a reproducible tensile force tests under successive thermal shock with tensile loading. Compared to the existing commonly used testing methods, new method avoided the problems arising for a pre-heated and subsequently pre-cooled test specimen for determining its tensile strength. The results indicate that thermal shock has great effects on the mechanical properties of the filter bag materials. The thermal shock played an important role in degradation of tensile strength. Furthermore, XRD and DMA analysis were employed to verify the above results, which demonstrated that the thermal shock effect on the microstructure of filter bag materials during the process. Hence, the results of new method for the determination of polyester filter bag materials tensile strength under simultaneous thermal shock with pre-tensile loading is more accurate and more sensitive. This study provides the technical reserves and theoretical bases for the research of the filter bag materials under thermal shock.

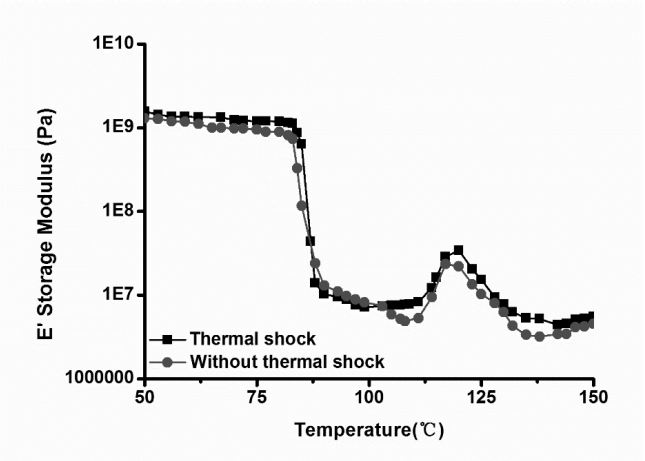


**Fig.5b.** Storage modulus of samples with pre-tensile loading under un-shock and thermal shock (twelve cycles)

## REFERENCES


1. Tanthapanichakoon W., Furuuchi M., Nitta K., Hata M., Endoh S., Otani Y., 2006, Degradation of semi-crystalline PPS bag-filter materials by NO and $O_2$ at high temperature. *Polymer Degradation and Stability*, 91(8): p. 1637-1644.
2. Limin B., Liu D.L., 2013, Damage characteristics of dry sand erosion of fiber in a hot environment. *Journal of Textile Engineering*, 59(1): p. 1-6.
3. Kishima T., Bao L., Nakazawa K., 2003, Experimental study about particle wear of the bag filters. *Soc Powder Technol JAPAN Preprints*, p. 55-57.
4. Limin B., Liu D.L., Danna Q., Kemmochi K., Yamanaka A., 2012, Measurement and evaluation methods for damage of fibers from dry sand erosion in a hot environment. *Textile Research Journal*, 82(15): p. 1612-1617.
5. Mangat M.M., Hes L., Bajzík V., 2015, Thermal resistance models of selected fabrics in wet state and their experimental verification. *Textile Research Journal*, 85(2): p. 200-210.
6. Pham M., Clark C., McKenna J., 2012, The evolution and impact of testing baghouse filter performance. *Journal of the Air & Waste Management Association*, 62(8): p. 916-923.
7. ÜNAL A. G. P. G., MYO E. Ü. E. A., TAŞKIN C., 2007, The effect of weave and densities on tensile strength of 100% polyester fabrics. *TEKSTIL VE KONFEKSIYON* 17(2): p.115-118.
8. Haji A., Rahbar S.R., 2012, Structure evolution and mechanical behavior of poly (ethylene terephthalate) fibers drawn at different number of drawing stages. *Chemical Industry and Chemical Engineering Quarterly*, 18(2): p. 233-243.
9. Yoo H.J., Kim K.H., Yadav S.K., Cho J.W., 2012, Effects of carbon nanotube functionalization and annealing on crystallization and mechanical properties of melt-spun carbon nanotubes/poly(ethylene terephthalate) fibers. *Composites Science and Technology*, 72(15): p. 1834-1840.
10. Shaw J.P., Gilbert M., 1991, Characterization of commercial polybutylenes. part II. Crystallinity and tensile properties. *Journal of Macromolecular Science, Part B*, 30(4): p. 301-317.
11. Aoki Y., Amari T., Nishimura K., Arashiro Y., 1999, Dynamic mechanical properties of poly (ethylene terephthalate) /poly(ethylene 2,6-naphthalate) blends. *Macromolecules*, 32(6): p. 1923-1929.
12. Rezaei F., Yunus R., Ibrahim N.A., 2009, Effect of fiber length on thermal mechanical properties of short carbon fiber reinforced polypropylene composites. *Materials & Design*, 30(2): p. 260-263.