"The development of a waterproof breathable polytetrafluoroethylene (PTFE) membrane as a moisture barrier for fire protective suits"

Swati Raj, D.S. Dubey, Akash Verma, Ajay Sharma, N. K. Singh*

Abstract

Polytetrafluoroethylene (PTFE) is a remarkable membrane material. Due to its high melting point, PTFE fine powder cannot be processed using the conventional melting processing methods. Instead, techniques such as paste extrusion, rolling and sintering have to be employed.

The water vapor transport properties of polymer membranes are critical in applications of waterproof breathable clothing materials. Several test methods are available for measuring the permeability of polymer membrane or laminates but they are either time-consuming or require large amounts of sample. A new test apparatus was devised for determining the water vapor permeability of polymer. Additionally, the water vapor transport behavior of the PTFE membrane does not depend upon the water content in the polymer.

Unsintered PTFE films were uniaxially stretched using Universal Testing machine at a speed of 100 mm/sec and sintered in the stretched position by blowing hot air of temperature 370^0C over it for 5 minutes and cooled down to room temperature. Sequential biaxial stretching of PTFE film has been done by first stretching in transverse direction and sintered in the stretched position and then stretched in longitudinal direction and sintered similarly as mentioned above. MVTR of both uniaxially and biaxially stretched films was determined by inverted cup method and the MVTR was found to be 4500 g.m-2.24 h-1 for uniaxially stretched and 5075 g.m-2.24 h-1 for biaxially stretched film as per ASTM E 96. These high values of Moisture Vapor Transmission Rate (MVTR) show good breathability of the films and are quite suitable for using as a waterproof breathable moisture barrier membrane for fire protective suits.

In addition, we describe a precision PTFE stretch operation with asymmetric heating system, and how it can be used to improve the properties of PTFE membrane. Different stretching ratio (none and 50%), asymmetry heating temperature (420ºC), and different heating time (5 and 10 s) were used to modify the PTFE membrane pore size. It was found that a higher stretching rate tends to result in larger pore size and broader pore size distribution at the same heating time. At a shorter

heating time and without stretch at asymmetric heating process, the porosity of PTFE membrane was increased from 50 to 70% and the mean pore size was decreased from 0.15 to 0.08 mm.
Key words: PTFE membrane films, WVTR, Different stretching ratio. Pore size control

1. Introduction

Fire protective clothing (Turnout gear) is being used in various fire fighting/ rescue operations. Presently a number of imported as well as indigenously developed fire protective apparels are commercially available in India. Turnout gear is comprised of mainly three separate components: the outer shell, the moisture barrier, and the thermal liner.

Outer shell: It provides resistance to flame and heat and also protects the gear from rips, tears, and abrasions.

Moisture barrier: It does not allow penetration of hot steam, hot gases and liquids from outside environment while still allowing permeation of water vapors from inside to the atmosphere.

Thermal layer: It acts as heat insulating layer which obstructs the passage of heat coming from fire to the firefighter. Thermal layer is made up of non woven fabric containing entrapped air which acts as thermal insulator.

Moisture barrier is an important component of fire protective suit for safety and comfort of the wearer firstly by preventing the water to enter the underlying thermal layer. Water, if enters into the thermal layer displaces the air and decreases the thermal insulation effect of the air that may lead to burn injuries. Secondly, the moisture barrier allows the escape of perspiration to reduce the metabolic heat buildup. Excessive heat buildup can lead to stress-related injuries for firefighters. To allow the escape of perspiration, the moisture barrier should be breathable.
Breathability is a property of materials and composites, which permits the escape of moisture and the heat associated with that moisture from the interior of the garment to the outside environment. During firefighting operations firefighters have to perform strenuous physical activities which lead to production of excessive heat. This heat produced through metabolic activity get entrapped in the heavy clothing of firefighter and leads to increase in the body core

temperature from 37^0C to dangerous levels and onset the heat stress. Heat stress can manifest itself in many different ways that include heat exhaustion, heat stroke, and ultimately death. The effects of heat stress may also include impairment of judgment and limit endurance. It has been reported that more than half the fatalities and a significant proportion of injuries to firefighters are linked to heat stress-related causes.

Though, breathability is a very important property for turn out gears, its importance has been realized only 10 years back. Prior to that time, most of the fire men wore protective coats and pants with impermeable coated barrier materials which lead to accumulation of sweat and heat stress causing uncomfortness to the wearer. Breathability of the turnout gear was measured by the moisture vapor transmission rate (MVTR) through the fabric, higher the MVTR of any fabric more is the breathability of the fabric. The heat associated with the moisture vapors transmitted through the fabric is assessed by Total Heat Loss (THL) test. The comfort ability of the fabrics increases with increase in THL. In the late 1990s, the International Association of Fire Fighters fought endlessly to have the total heat loss test implemented as part of the NFPA 1971 standard for turnout gears. As a result, the sixth edition of NFPA published in year 2000 has introduced the requirement for evaporative heat transfer through garments by total heat loss test. Breathable fabric for application in turn out gear should have minimum total heat loss value of 205 W/m^2.

At present, most of the turnout gears available in Indian market have neoprene rubber coated fabric as moisture barrier and have no ability of permeation to moisture vapors. This leads to accumulation of water vapors inside the clothing and gives uneasiness and burns during fire fighting operations. Moreover, at high temperature neoprene degrades into toxic halogenated by-products since the degradation temperature of neoprene is 149^0C.

In International market, very few companies are making waterproof breathable garment such as Goretex which is very expensive and not available even through import. Also the formulation & composition of waterproof breathable fabric available internationally is closely guarded secret and mentioned nowhere in literature.

In view of the above, there is an urgent need to develop a proper moisture barrier with dual functions which is able to release moisture vapors of perspiration from body to the outside atmosphere but does not allow liquid water to penetrate down to the body.

2. Experiment

2.1. Uniaxial Stretching of Unsintered Poly(tertafluoroethylene)

Unsintered Poly(tetrafluoroethylene) (PTFE) films were obtained from Tonk and Associates, Meerut, U.P. The unsintered PTFE films of size 6 x 4 cm were stretched by using Universal Testing Machine (UTM). The stretching speed was adjusted at 100 mm/min. The stretched films were then sintered by circulating hot air of temperature 370^0C for 5 minutes while clamped in the stretched position. The films were then cooled to ambient temperature and removed from UTM clamping and tested of Water Vapor Transmission Rate (WVTR) by inverse cup method (ASTM E 96).

2.2. Biaxial Stretching of Unsintred Poly(tertafluoroethylene)

Another 6 x 4 cm sized sample of unsintred poly(tertafluoroethylene) was first stretched in longitudinal direction at same stretching speed of 100 mm/min. After that it was sintered as above and cooled at ambient temperature. Then the sample was removed and clamped again in transverse direction and sintered at the same temperature 370^0C for 5 min. and cooled again at ambient temperature. This caused amorphous locking within the film. The film was then removed from UTM clamping and tested of Water Vapor Transmission Rate (WVTR) by inverse cup method (ASTM E 96).

3. Results and discussion

WVTR Test

In WVTR test we have used invert cup method because our sample comes in contact with water during services.

A glass cup was used for WVTR test and filled with distilled water up to ¾ of cup capacity. The specimen was attached to the mouth of test cup and weighed. The test cup was clamped in inverted position and kept as it is for 24 hours. The test cup was reweighed after 24 hrs and WVTR was calculated as below.

Weight of cup with water before 24 hrs was 183.534 gm.

Weight of cup with water after 24 hrs was 179.948 gm.

Weight of water transmitted was (183.534 – 179.948) = 3.586 gm

The area of the cup from which water vapor transmitted was 0.0471 m^2

Sr. No.	Sample	WVTR (av. of 5 samples) ($g.m^{-2}.24\ h^{-1}$)
1.	Uniaxially Stretched Unsintered PTFE	4500
2.	Biaxially Stretched Unsintered PTFE	5075.7

WVTR Test Reading

4. Conclusion

Unsinterd PTFE film was stretched uniaxially and biaxially by UTM and then tested for WVTR. The uniaxially and biaxially stretched PTFE film shows very high WVTR, and the biaxially stretched PTFE film showed higher WVTR than uniaxially stretched PTFE film. The high value of WVTR in case of biaxially stretched PTFE film was due to the development of higher number of microspores then uniaxially stretched PTFE film. These microporous expanded PTFE membrane are quite suitable for using as a waterproof breathable moisture barrier membrane for fire protective suits.

Acknowledgements

References

1. Plastics Materials seventh edition by J. Y. Brydson.
2. Pauling, L., The Nature of Chemical Bond, 3rd ed., Cornell Univ. Press, Ithaca, N.Y., 1960.
3. Wikipidia.com
4. Fluoroplastics Volume I, Non-Melt Processible Fluoroplastics The Definitive User's Guide and Data book

5. Robert W Gore, Process for Producing Porous Products, U. S. Patent 3,953,566, to W. L. Gore & Associates, Inc., Newark, Del.
6. Willian G. Ellis. Protective garments U. S. Patent 4,034,417 to Can – Gard Protective Wear Ltd.
7. STD - ASTM E96 - ENGL 2000 Standard Test Method For water Vapor Transmission Rate.
8. Pore size control of PTFE membranes by stretch operation with asymmetric heating system Lei-Ti Huanga, Ping-Shun Hsua, Chun-Yin Kuoa, Shia-Chung Chena,b, Juin-Yih Laia R&D Center for Membrane Technology and Department of Chemical Engineering, Chung Yuan University, Chungli 320, Taiwan
9. Theresa Ribicic, Fireman'sTurnout coat, U. S. Patent 5,189,737 to Ramwear, Inc., Mentor, Ohio.
10. Plunkett, R. J., US Patent 2,230,654, assigned to DuPont Co., Feb. 4, 1941.
11. Plunkett, R. J., "The History of Polytetrafluoroethylene: Discovery and Development," in *High Performance Polymers: Their Origin and Development*, Proceed. Of Symp. on the Hist. of High
12. Perf. Polymers at the ACS Meeting in New York, April 1986, (R. B. Seymour and G. S. Kirshenbaum, eds.), Elsevier, New York, 1987.