Effects of Environmental Stress on the Reliability of Flame and Heat Resistance Fabrics for Firefighters Clothing

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Abstract

Methods to evaluate the useful life time of flame and heat resistance fabrics for firefighters clothing were studied. As part of this study, the effects of individual environmental stress on the durability of Nomex fabrics for firefighters were investigated to improve the reliability assessment method for firefighter's clothing.

We estimate the failure of Nomex fabrics with degradation of tear resistance and heat transmission performance. Five environmental stresses were chosen to simulate the use in the field. These factors are weathering with UV ray, radiation from heat, flexing, abrasion and cleaning procedures. 2-factorial experimental design was used to analyze the effects of five individual environmental factors on the failure of Nomex fabric. As a result, we found the main failure cause of Nomex fabrics were UV ray and radiation heat.

Keywords: protective clothing, firefighters clothing, reliability

1. Introduction

Protective clothing worn by forefathers is an important element of their gear, as it affects their safety, comfort, and mobility. The clothing worn by today's firefighter is the result of a great deal of research over the past few decades into new fabrics, garment designs and test methods. However, much of this research has been concerned with the performance of new fabrics and clothing with little focus on the performance of clothing over its entire lifetime, and the retirement of it. But the lifetime performance of flame and heat resistant fabrics for firefighters is important as much as their initial properties, considering these fabrics are products to be used for their service life.

Flame and heat resistant fabrics for firefighters is important and indeed in certain circumstances is vital for survival. The human body must be kept within a narrow temperature range, prolonged exposure to temperature outside this range can result in death. Therefore, flame and heat resistant fabrics for firefighters should kept their performances until their retirement although fabric performance can be lost by frequent washing, flexing, abrasion, weathering, stored heat etc.

But, it is difficult to estimate the useful lifetime of protective clothing for firefighters and to determine when to retire an individual set of turnout gear. While some degradation of this clothing is easy to detect, such as rips in the outer shell, other forms of degradation may not be as apparent when the garment is inspected visually. Therefore, it is required to develop the testing method for determining the useful lifetime of flame and heat resistant fabrics.

In this study, we tried to estimate the useful lifetime of flame and heat resistant outer shell fabrics for firefighters by the application of the reliability theory. At first, the effects of individual environmental stress on the durability of Nomex fabrics for firefighters were investigated to find the actual stress factors affecting the degradation of fabrics before designing accelerated stress test.

2. Experimental

2.1 Samples

We used Nomex as flame and heat resistant fabric samples. Material specifications are indicated in table 1.

Table. 1. Material specification

Material	Normex
Construction	Ripstop
Density(ends/cm*pick/cm)	16*16
Thickness(mm)	0.688
Weight (g/m^2)	257.1

2.2 Research process

At first, we performed the field studies to survey the actual using conditions of firefighter's clothing including the environments, the frequency of use, the time of use and the expected service life in the field. And then, from the information of these field studies, we assumed the stress factors considered to affect the durability of the outer shell fabrics for firefighters. These environmental factors were reproduced at a laboratory level simulating the using conditions of the field.

In this study, five environmental factors were chosen as stresses, which were weathering with UV ray, radiation from heat, flexing, abrasion and cleaning procedures. The expectancy of service life was surveyed as 5 years and the time and the frequency of use were also obtained from the study.

Based on the five assumed environmental factors obtained from the field studies, we designed 2^n factorial experiments to find the actual factors affecting the useful lifetime of flame and heat resistant fabrics. And then we analyze the effects of five individual environmental factors on the failure of Nomex fabrics.

2.3. Testing methods

In this study, step test was designed to simulate the use in the field. Testing procedure reproducing the using conditions of the field at a laboratory level is as follows.

1) Exposure to UV Light Samples were exposed to UV light for 68 light hours corresponding to actual 5 year service life in the field, using Weather-O-meter at an irradiance level of 0.35 W/m^2@340nm with CIRA(Inner) and Soda lime(outer) filters according to **ISO 105-B04**.

2) Exposure to heat radiation In this study we irradiate radiant heat on the samples for 14 kW/m^2 for 14 hour and 40 kW/m^2 for 28 minutes corresponding to actual 5 year service life using testing machine based on ISO 6942.

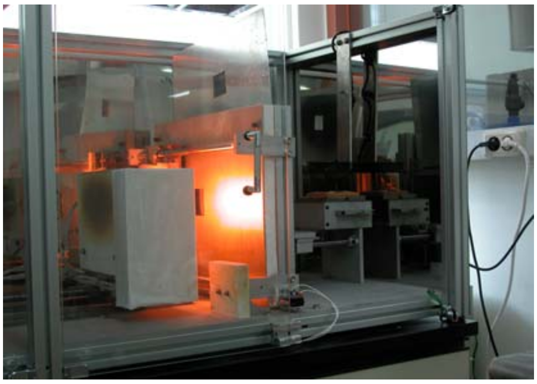

Figure 1. Radiant heat aging machine corresponding to ISO 6942

3) Flexing and abrasion Flexing and abrasion were treated 470,000 times and 67,000 times on testing machine corresponding to ISO 7854 and ASTM F 4157 respectively.

4) Washing Samples were stressed under cleaning procedure based on ISO 6330.

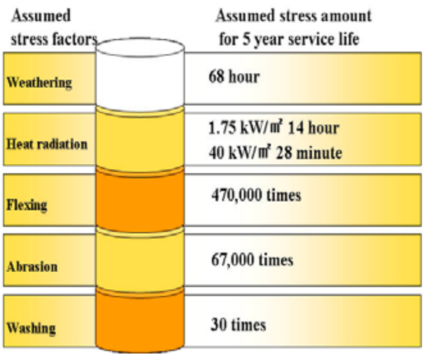

Figure 2, Assumed stress amount for actual 5 year service life

5) Evaluation of degradation of samples

After (1)~(4) aging processes, the degree of degradation was evaluated by tear strength and the fraction of heat transmitted through a specimen exposed to a source of radiant heat, based on ISO 9073-4 and ISO 6942 respectively.

3. Results and Discussion

3.1. Significant factors affecting the degradation

The results of the statistical analysis for 2^n factorial experimental design were showed in Table 3 and Table 4. From Table 3, we found that weathering and radiant heat are significant factors of each 5 stresses which affect the degradation of tear strength. Heat transmission was not affected significantly by the five environmental factors. The result was shown in Table 4.

Table 3. Variance analysis table of the result of tear strength

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	5	88473.38	17694.68	3.58	0.04
Error	10	49466.55	4946.65		
Corrected total		137939.93			

Source	DF	Anova SS	Mean Square	F Value	Pr > F
weathering	1	52729.94	52729.94	10.66	0.01
Radiant heat	1	30364.81	30364.81	6.14	0.03
bending	1	223.95	223.95	0.05	0.84
abrasion	1	5058.05	5058.05	1.02	0.34
washing	1	96.63	96.63	0.02	0.89

Table 4. Variance analysis table of the results of heat transmission factor

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	5	93.08	18.62	0.61	0.70
Error	10	305.51	30.55		
Corrected Total	15	398.59			

Source	DF	Anova SS	Mean Square	F Value	Pr > F
weathering	1	66.71	66.71	2.18	0.17
Radiant heat	1	6.01	6.01	0.20	0.67
bending	1	0.00	0.00	0.00	1.00
abrasion	1	0.22	0.22	0.01	0.93
washing	1	20.14	20.14	0.66	0.44

3.2. The effect of weathering on the degradation of tear strength

Tear strength were decreased linearly as the weathering hour increased.

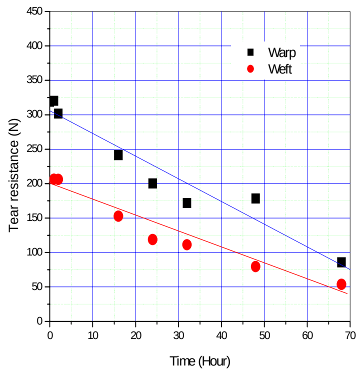

Fig. 3. The relationship between tear strength and weathering hour

3.3. The effect of radiant heat irradiation on the degradation of tear strength

Tear strength decreased quickly with the initial exposure to 40 kW/m^2 radiant heat, while they were decreased slowly with the exposure to 10 kW/m^2 and 20 kW/m^2 as the time of irradiation increased

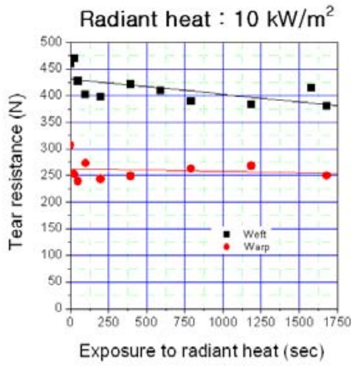

Fig. 4. The relationship between tear strength and the exposure time to 10 kW/m^2 radiant heat

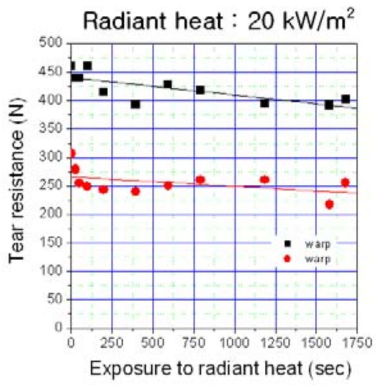

Fig. 5. The relationship between tear strength and the exposure time to 20 kW/m^2 radiant heat

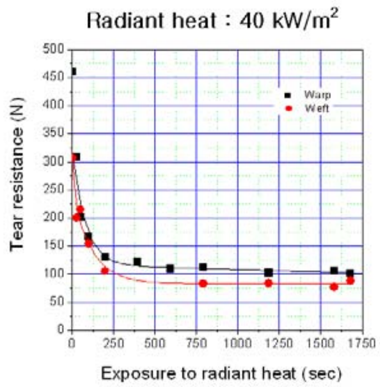

Fig. 6. The relationship between tear strength and the exposure time to 40 kW/m^2 radiant heat

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