The Study of Flame Engulfment Protection of Firefighter's Clothing

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Abstract

The study determined the protection of firefighter's clothing while the clothing faced flashover and explosion condition. 8 different kinds of firefighter's clothing put on an instrumented manikin under flame engulfment measured the burning degree, burning area ratio and the highest temperature and the average heat flux per body segment through the burn risk calculation of the temperature sensors on the manikin surface. The result showed that while FTJAP was the most serious burn risk with 70% surface area of 3rd degree burning, FTUSA was the only one affected by 10% surface area. The appearance of firefighter's clothing after flame engulfment was also analyzed. The analysis indicated that the more integrity the inner layer of clothing had after exposure, without brittleness and shrinkage, the more protection the clothing was. At the same time, the accessories on the firefighter's clothing were also crucial, especially for membrane and retro-reflective stripes. If they shrink in the exposure of flame, the protection of the clothing would reduce.

Keywords: protection, manikin, flashover, explosion condition, heat flux

1. Introduction

High insulation and energy conservation design popular in recent architecture increase the threat of fire scene to firefighter once fire took place. Building with good thermal insulation would more easily lead to flash-over condition. Moreover, if the building was burned in starved oxygen due to lack of well ventilation, fire growth could become flash-over condition in subsequence. At the same time, the assistance of smoke detector, fire alarming system, and network of firefighting operation, firefighters could arrive fire scene before the fire reach to mature state which meant a structure fully involved in fire. Unfortunately, firefighter possibly could enter the building just as flash-over take place. Then, during the moment of flash-over condition, they will face the fire scene which suddenly changed to an extremely danger condition. Moreover, during the recession of fire scene with lack oxygen situation, fighters rushing into fire scene could cause combustion and explosion takes place because of the input of oxygen. The condition also makes firefighters sink into the dangerous of environment in which they was surrounded in heat, flame and radiation rushing out the building. Therefore, firefighters not only are required to understand the process of forming the fire scene, but also absolutely follow safe and effective way for firefighting as well as recognize the limitation of their fighting gear. [1]

The main design of firefight clothing is to avoid the heat injury as firefighters approach to fire scene. The threat includes the danger of heat radiation, heat convection, and hot surface. The level of burn injury for firefighter wearing protective clothing is related to heat exposure, firefighting activity and the structure of protective clothing. [2]

Today, the assembly of firefighting clothing commonly includes the fireproof out layer, barrier layer and inner layer. The out layer prevents body skin from the exposure of heat radiation or flame. The barrier provides both the performance of waterproof and heat insulation. The waterproof layer can either completely prevented from water penetration in liquefied and vaporized state, or only prevent liquefied water penetration. The thermal barrier is the layer which can resist heat flow rapidly crossing the clothing. The quality of thermal barrier mainly depends on the heat transmittance property of the fireproof material and the air space made by this layer. Therefore, fire protective clothing is designed principally to creating a microclimate environment in which the impact of heat and moisture transmittance can be buffered. [3] However, there is still lack of information for the performance of firefighting clothing in flash over condition. The study which focused on the protection of different firefighting clothing under flame engulfment condition may complement the knowledge of firefighting suit.

2. Testing Material

Eight types of firefighter’s clothing were prepared by TTRI and EMPA. The material and basic properties of garments were listed in Table 1.

3. Testing Method

The test was accomplished by the use of EMPA’s Henry manikin under flame engulfment condition, following the requirements of the former ISO DIS 13506.2. According to ISO DIS 13506.2, the 12 gas flame burners were adjusted to reach an average heat flux of 84KW/m^2 suffered by the manikin. 122 T-type thermocouples on the manikin monitored the temperature course during the measurement to calculate the heat flux and to predict the burning risk in the body area where the sensor was positioned. Before and after the measurement, the assemblies on the manikin were photographed and evaluated.

Table 1 Properties of the protective clothing

Code	Out shell	Moisture Barrier	Thermal Liner	Weight
FTJAP	100% Cotton coated with Aluminum powder	None	None	1977g
FTUSA	100% Nomex quilt	Neoprene + Polyester/ Cotton fabric	100% Nomex III	2728g
FTCTI	Preoxidized PAN + Para-aramid	Gore-Tex + Nomex nonwoven	100% Aramid nonwoven + 100% Nomex RS lining	1956g
FTEUR	100% Nomex Delta TA	Sympatex + Nomex /Viscose FR backing	100% Aramid nonwoven + Nomex/Viscose FR lining	1617g
FTTWN	60%Kevlar + 40% Nomex	Sontara E89 + FR Aerotex membrane	100% Sontara E89 quilt + Nomex/Viscose FR lining	1613g
FTIMP	Nomex III + impermeable PU coating	impermeable PU coating on the inner side of outer shell	Wool and FR viscose lining	1733g
FTLEA	Chrome tanned goat leather	None	Aramid fleece (kermel)/quilted with FR viscose lining	3287g
FTBRE	Nomex Omage	Goretex membrane laminated to fleece	Aramid fleece (Nomex)/quilted to FR viscose lining	1829g

4. Result and Discussion

4.1 Total burnings

Fig.1 showed the percentage of different predicted burns for the whole body. The FTJAP sample exhibited the highest percentage of 3rd degree burnings. This was due to the low thermal resistance of the jacket and the fact that it shrunk during the test. In fact, the jacket had to be cut off from the manikin after the testing. However, it had been expected to get good result that the loose fit of FTJAP should offer large air layers, and the long style of the jacket should provide a considerable overlapping area to the trousers. But in flame engulfment condition flames may find ways under the jackets at the hem or other edges to cross. As Fig.1 was compared with Table 2, it showed that the better the thermal insulation of the clothing such as FTUSA and FTBRE, the less percentage of serious burning the manikin.

Table 2 The thermal resistance of 8 kinds of firefighting clothing integrating with a cotton underwear.

Unit:℃×m^2/W	Thermal resistance
FTJAP	0.153
FTUSA	0.454
FTEUR	0.336
FTCTI	0.385
FTTWN	0.278
FTIMP	0.282
FTLEA	0.358
FTBRE	0.391

4.2 Burning of Chest, Abdomen and Back

The result of Fig.2, Fig.3 revealed that, except FTBRE and FTCTI, the burning of the front is less severe than that of the back because the front of these clothing is additionally protected by overlapping and pocket. Moreover, the influence of the posture of manikin slightly leaning backwards also seems not to be neglected. Interestingly, almost 90% of the sensors at back shows 3rd degree burning for sample FTJAP but only 54% at the front.

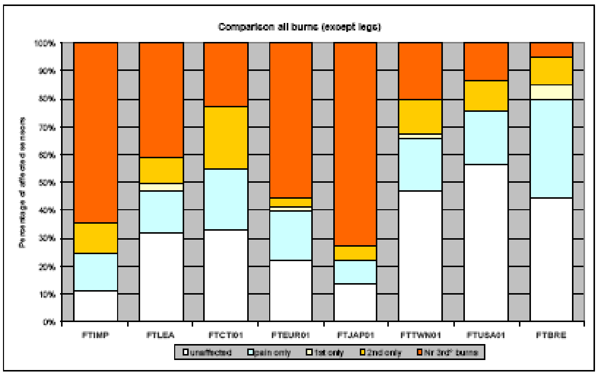

Fig.1. Comparison of the tested samples regarding expected burns on total body

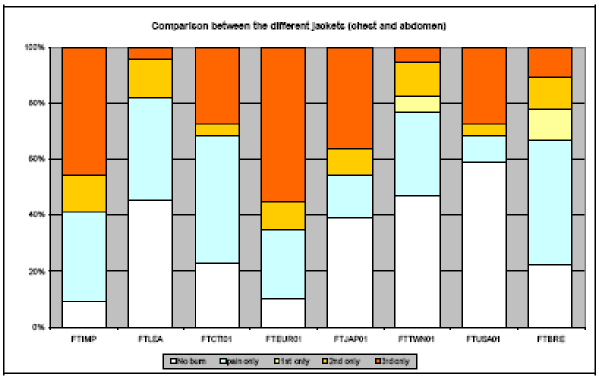

Fig.2. Comparison of the tested samples regarding expected burns on chest and abdomen

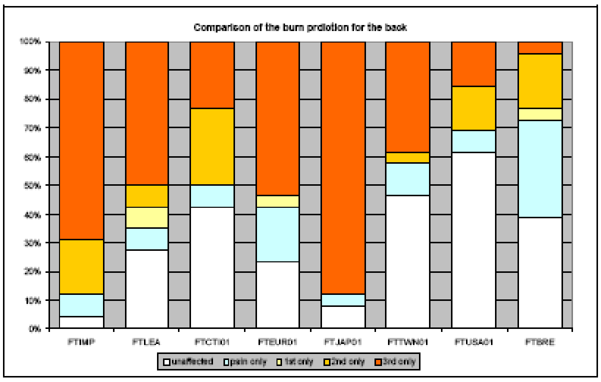

Fig.3. Comparison of the tested samples regarding expected burns on the back

4.3 Afterburning

While the flame impacted to manikin, the sensors on the manikin showed the rapid increase of temperature. After the burners extinguished, the temperature had been rising and than falling gradually afterwards. The temperature rose resulted from the energy still held in the clothing system, and slowly dispersed into test room. Although the material of firefighting clothing was of fireproof, the accessories and retro-reflective strips of the clothing were able to melt or ignite. Under the condition, the exposure time of high temperature state for the manikin was prolonged and the percentage and level of burnings would increase. Especially, the flames on the sample FTJAP had to be extinguished after the test since still some burning spots existed after 90sec. All other sample extinguished automatically after the time stated in Table 3.

Table 3 Extinguished time for Afterburning

Code	Afterflame Time	Max. Temp.	Max. Heat flux
FTJAP	90	83.0	5.59
FTUSA	4	59.5	1.85
FTEUR	55	78.9	3.01
FTCTI	4	64.1	2.55
FTTWN	5	56.3	2.05
FTIMP	10	73.7	1.94
FTLEA	40	80.7	1.96
FTBRE	6	55.2	2.41

4.4 Maximum temperature per body segment

The maximum temperature on body can imply if there are some weaknesses or differences among those parts. Moreover, the effect of the material in different parts can also be analyzed. Table 2 showed that the clothing of the highest temperature below 60℃ were FTTWN (on upper back), FTUSA (on abdomen), FTBRE (on abdomen). Those of the highest temperature below 80 ℃ were FTCTI(on chest), FTIMP(on back), FTEUR(on right arm). Those beyond 80℃ were FTLEA(on left arm), FTJAP(on left arm). Therefore, the result inferred the position of the highest temperature happened on the torso of the manikin.

4.5 Average heat flux per body segment

The risk of getting burns strongly depends on the amount of energy passing through fabric. Table2 also showed the result that the Maximum heat flux below 2 kW/㎡ among these clothing were FTUSA, FTIMP, FTLEA. Those below 3 kW/㎡ were FTTWN, FTBRE, FTCTI, FTEUR, FTJAP were beyond 3 kW/㎡. Interestingly, the ranking does not correspond to the list of maximal temperatures in spite of the dependency of heat flux and temperature rise.

4.6 The total appearance after the testing

The result showed the potential further strain after burning for textile material used in a firefighters assembly is required to be considered. Especially materials which tend to melt at higher temperatures such as FTTWN after being subjected to such high heat flux. Normally the membranes and highly reflective stripes are most affected by the testing state. While the polymers of those shrink and melt before they disintegrate. The phenomenon can lead to a deformation of the garments surface which causes the existing air layer in garments vanished. Besides, polymers store a lot of energy during the process which will be given off after the actual flame exposure. Therefore, burnings might occur at this stage.

If the whole fabric is made from the materials which shrink while exposed to heat, the protection of the garment is reduced drastically like FTJAP. All tested samples tend to change color and get brittle during flame exposition. However, FTEUR after the flash over test looked intact but fell apart when taken from the manikin. Although FTBRE and FTUSA showed more or less severe damages after the flame engulfment test, the inside of the garments were kept intact. Therefore, the visible damages correspond roughly to the calculated burn risk described in the previous paragraph, i.e. the jackets with the low visible damage in inner layer render the low burning percentage.

5. Conclusion

The study indicates that the clothing system can rendering good protection under flame engulfment condition is not only determined by high thermal insulation value of clothing system but also the fireproof material of the outermost fabric. Of course, this based on the material of the clothing system can keep inner layer intact under the tested condition. Therefore, the jackets with good thermal insulation and the least damage on inner surface such as FTUSA and FTBRE have the best protection. The sensitive parts of firefighter jackets such as membranes and retro-reflective stripes also affect the performance of protection if those materials shrank when encountering flash over condition. Coating with aluminum may have a beneficial influence in radiant heat protection, but do not offer a good protection against convective heat, such as FTJAP during the flame engulfment test.

References

[1] F. J. Abeles, Del Vecchio R.J., Himel V.H., A Firefighter's Integrated Life Protection System. Phase I: Design and Performance Requirements. Gruman Aerospace Corporation, New York (1973).

[2] H. W. Duncan, G. W. Gardner and R. J. Barnard, Physiological responses of men working in fire fighting equipment in the heat, Ergonomics, 22 (5), pp. 521-527(1995).

[3] V. Louhevaara, R. Ilmarinen, B. Griefahn, C. Künemund, H. Mäkinen, Maximal physical work performance with European standard based fire-protective clothing system and equipment in relation to individual characteristics, European Journal of Applied Physiology, 71(2-3), pp. 223-229(1995).