

**STUDY OF THERMAL PROTECTION AND
FLAMMABILITY CHARACTERISTICS OF TEXTILE
ASSEMBLIES USED IN MILITARY APPLICATIONS**

by

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to the



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***Dedicated to valiant IAF pilots
whose lives were lost in crash fires***

Certificate

This is to certify that the thesis entitled **“Study of Thermal protection and flammability characteristics of textile assemblies used in military applications”** being submitted by Mr. T M Kotresh, to the Indian Institute of Technology, Delhi, for the award of the degree of Doctor of Philosophy in the Department of Textile Technology is a record of bonafide research work carried out by him. Mr. T M Kotresh has worked under my guidance and supervision and fulfilled the requirements for the submission of the thesis.

The results contained in the thesis have not been submitted, in part or full, to any other University or Institute for the award of any degree or Diploma.

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ABSTRACT

This thesis is an attempt towards the comprehensive investigation of the protective clothing and seating assemblies used by the fighter pilot under high intensity heat utilizing cone calorimeter; to understand the role of various layers and their order in an assembly in delaying ignition, suppressing peak heat release rate and total heat release in offering protection and to identify a suitable clothing assembly that offers higher level of protection in the event of unforeseen fire.

Despite the significant advances that have taken place over a period of time in the design of seats for the aviation sector, it is perplexing that the fighter aircrafts still utilise a flammable nylon fabric cover to enclose the highly flammable polyurethane (PU) foam. This work reports the comprehensive burning behaviour of the PU foam in combination with currently used nylon fabric cover and the flame retardant fabrics viz., Nomex, Nomex III and Basofil fabric, at wide ranging levels of heat flux in cone calorimeter.

The effect of the flame retardant fabric cover was evident in the drastic reduction of the peak heat release rate (PHRR), the most important single parameter in any fire. A simple model was put-forward, based on the visual observations during the experimental runs, to explain the reduction in the ignition times for the foam-fabric combination vis-à-vis the foam alone. With the increasing levels of heat flux, the burning behaviour of the foam-fabric combination changes from one-step decomposition at lower levels of heat flux to two-step decomposition at higher levels of heat flux. The noted behaviour was explained on the basis of the interaction between the foam and the fabric as noted from the morphology study of the underside of the fabrics. The coating of the foam was also observed physically on the underside of the fabrics. The noted coating offers the tortuous

path for the escape of the vapours from the foam as corroborated from the permeability studies.

The effect of permeability of the fabric on the burning behaviour of the foam-fabric was studied by using nylon and Nomex III fabric. Various levels of permeability were created by punching holes of 2 mm dia at fixed distance on the surface of the fabric exposed to radiant heat. While the varying permeability of the nylon fabric did not have any impact on the burning behaviour of the foam-fabric combination, the flame retardant fabric cover revealed interesting results. At low levels of permeability, the burning behaviour of the foam-fabric combination was governed by the fabric cover; and at higher levels of permeability, the burning behaviour was governed by the foam. The study revealed that the high levels of permeability are not desirable for a flame retardant cover. The effect of permeability of the fabric on the burning behaviour of the foam-fabric combination was investigated for the first time.

Further, the study of effect of air permeability on the burning behaviour of the combination by using multiple layers of fabric over the foam revealed the reduction in the PHRR and the enhancement of the ignition time. Based on the results, it was felt that the permeability of the fabric should be considered in the burning behaviour of foam-fabric combination.

In the background of the absence of reported investigations on the entire assembly of protective clothing used by the fighter pilot, a detailed investigation was carried out on the burning behaviour of the assembly in the present work. The work investigated the role of surface fabric, nature of bladder material, aluminium foil at various positions, aluminium paste coating and the intumescent coating mainly to understand the burning

behaviour from the point of view of delayed ignition and the reduction of the heat release of the assembly.

Burning behaviour of assemblies consisting of nylon surface fabric in combination with natural rubber bladder (NR), Neoprene coated nylon fabric (NCNF) and PU coated nylon fabric (PUNF) revealed that the assembly with the NCNF had considerable reduction of PHRR. NR, even in combination with Nomex surface fabric had high PHRR. Same trend was noted with the combination of Thinsulate material covered by Nomex fabric as the surface layer. The investigation revealed that the burning behaviour of the assembly is governed by the burning behaviour of the flammable material. Surface fabric, even if flame retardant, will not affect the burning behaviour in case the underlying material is flammable, as noted from the investigation. It is only when both the surface fabric and the underlying bladder material are flame retardant or heat stable that their combination is able to show a synergistic effect in bringing down the heat characteristics even below the individual values of the components.

Burning behaviour of varying weights NCNF and NR in single and multiple layers was investigated. Unlike the multiple layers of NR exhibiting burning as a single entity, NCNF was found to exhibit delayed burning as revealed by the saw-tooth HRR curve. The presence of nylon fabric was found to delay the burning of layers, as noted by the TGA studies, leading to saw-tooth shaped curve. NCNF of higher weight was found to have low PHRR as compared to the lower weight NCNF consistently over a wide range of heat flux levels considered in the present study.

Use of aluminium foil, as expected, was found to be very effective in enhancing the ignition time of the assembly as the top layer mainly due to the high reflectivity as noted by the

measured optical properties. However, on ignition the assembly burned as the control. The most interesting result was the reduction in the PHRR and the total heat release (THR), when the aluminium foil formed the last layer in the assembly. The noted behaviour was attributed to the heat-feed back mechanism to the assembly leading to higher mass loss rates leading to the escape of the vapours unburnt. Even in the thermal protection studies, aluminium foil as the last layer was found to offer higher protection. This finding is significant from the design of clothing for the pilot, as the aluminium foil could be effectively used as the bottom-most layer.

Intumescent coated nylon fabric assembly was found to effectively block the passage of heat and lead to altered burning behaviour of the whole assembly leading to minimum heat release. However, the advantage of reduced heat release is offset by the enhanced weight penalty of the assembly.

Based on the study, an Anti G suit suitable for fighter plane pilots, using the Nomex fabric and NCNF bladder material was developed and was found to be acceptable in all the frontline fighter aircrafts of Indian Air Force. The combination is very unique and not available with any of the frontline Air Force units of the world.

The present study is, probably, the first of its kind that investigated the assembly of fabrics and the seat assemblies meant for the pilots by using cone calorimeter to evaluate the flammability parameter of the assembly in terms of the delay in ignition time and the post-ignition characteristics in terms of heat release. The findings of the study yielded valuable inputs for the development of clothing assemblies and has demonstrated the utility of cone calorimeter as a tool for the evaluation of assemblies.

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