

**DYNAMIC STUDIES ON SHELL MATERIALS AND VENTILATION
IN MOTORCYCLE HELMETS**

by

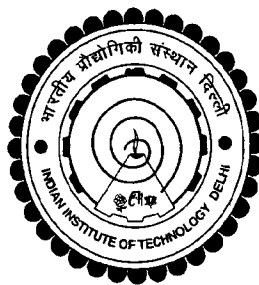
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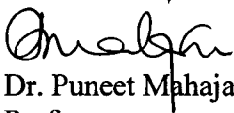
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CERTIFICATE

This is to certify that the thesis entitled **“DYNAMIC STUDIES ON SHELL MATERIALS AND VENTILATION IN MOTORCYCLE HELMETS”** being submitted by **PRAVEEN KUMAR PINNOJI** is a record of bonafide research work carried out by him under my supervision. This thesis has been prepared in conformity with the rules and regulations of Indian Institute of Technology Delhi, New Delhi. I further certify that the thesis has attained a standard required for the award of the degree of “Doctor of Philosophy”. The research reported and results presented in the thesis have not been submitted in part or full to any other institute or university for the award of any degree or diploma.



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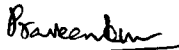
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(Praveen Kumar Pinnoji)

ABSTRACT

Helmets are widely used by two-wheelers for protecting the head against impact during an accident. In tropical countries to encourage people to wear helmets the impact protection has to be combined with ventilation and light weight. The thesis is focused on these two aspects so that the existing helmets can be improved. The investigation is carried out in two phases: first, airflow in ventilated helmets and their impact characteristics are determined; second, impact performance of helmets with various materials for outer shell is studied.

The conventional helmets are modified in two stages for improving the ventilation: first, with grooves and slots; second, with foam blocks on the inner surface of liner foam by lifting the helmet. The air flow in helmets is simulated using a commercial computational fluid dynamics (CFD) software code and a standard k- ϵ physical turbulence model is used. Various designs of ventilated helmets have been simulated and air velocities in these are compared with those in a conventional helmet. Higher air velocities are observed with a tangential slot and an increase of groove size in the helmet.

Impact tests are performed on commercial helmets for dynamic characterization and validation of the numerical model. Finite element analysis has been carried out on conventional and ventilated helmets. A three-dimensional finite element model of human head is used and assumed as rigid for predicting the peak acceleration and Head Injury Criterion (HIC) and as deformable for predicting the stresses in the brain tissue. A non-linear finite element code, with explicit time integration scheme is used for impact numerical simulations. The biomechanical characteristics of head such as brain stress, intracranial

pressures, cerebrospinal fluid (CSF) energy absorption are investigated for conventional and ventilated helmets for standard impact sites.

Impact behaviour of a composite shell for motorcycle helmet is investigated. In a composite, intra-ply damage and delamination are the principal modes of failure and energy absorption. Numerical studies are performed on helmets with outer shell of carbon/epoxy $[0_3/90_3]$ laminate. The damage in the lamina level is analyzed by using Hashin's failure criterion which is based on physical modes of composite failure. The delamination which is also called as interfacial fracture is examined by 'cohesive zone model' based on the fracture mechanics principles. Cohesive elements are introduced between the plies to simulate the initiation and propagation of the delamination front. Matrix tensile and compressive damage are observed at low impact velocities and followed by dynamic delamination at higher impact velocity. The increase in energy absorption in the composite shell, though marginal, is increased due to this damage and consequently force experience by the head is reduced compared to the composite shell without the damage.

Finally, the thesis presents the impact behavior of helmets with metal foam outer shells. Experiments and finite element analysis are carried out on metal foam helmets and a good agreement is obtained between the two. Energy absorption per unit mass is higher in aluminium foam shells with low density. The weight of the outer shell with low-density aluminium foam is reduced by approximately 70% compared to the conventional ABS shell.

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