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DYNAMIC STUDIES ON MOTORCYCLE HELMETS

PINNOJI * P.K. and P. MAHAJAN** P.

ABSTRACT

Threes different motorcycle helmets were studied here to investigate the dynamic performance. First is helmet with Acrylo-Butadiene Styrene (ABS) shell, second is helmet with metal foam, and third is helmet with single groove and slot for providing the ventilation. Computational fluid dynamics studies show considerable improvement in air velocities inside the helmet in the presence of grooves and slot. Front impact analyses with all the helmet models were carried out at 7 $m.s^{-1}$ velocity. Forces, Head Injury Criterion (HIC), and acceleration were evaluated by considering head as a rigid and found not to change significantly due to the presence of groove and slot in the helmet. The dynamic performance of a helmet with outer shell as metal foam was examined and compared with ABS material.

KEY WORDS

Helmets, Ventilation, Impact dynamics, Metal foam and Finite elements.

* Research Scholar, Dept. of Applied Mechanics, Indian Institute of Technology Delhi, India.
** Professor, Dept. of Applied Mechanics, Indian Institute of Technology Delhi, India.

INTRODUCTION

Motorcycle helmets protect wearer's head during the accidents or falls. In India, excessive sweating and resulting discomfort due to hot and humid weather conditions discourages motorcycle riders from using helmets unless it is mandatory by law. To enhance the evaporation of sweat and minimize the discomfort, grooves and slot were provided within the helmet geometry. Computational fluid dynamics (CFD) analysis was carried out for few ventilation models in helmets to study the air flow. Finite element analyses (FEA) for front impact simulations were performed to see if the presence of groove has a detrimental effect on the dynamic performance of the helmet.

One more way in which helmets can be improved is by lowering their weight by using alternative material for the shell. Lately, metal foams are being used in crash applications because of its light weight, high strength and energy absorption capabilities. Impact studies were carried on helmets with metal foam shell and their performance compared with Acrylo-Butadiene Styrene (ABS) shell helmet. The metal foams are expensive but much lighter than the ABS, which commonly used as material for shell.

VENTILATION IN HELMETS

There are many ventilation designs available in the market but none of them has been found or quoted for the optimal ventilation. Our main interest, here, was to observe the changes in velocity in the gap of head and helmet if groove and slot were provided inside the helmet. We investigate, here, air velocities inside the helmet using Computational fluid dynamics techniques. Few ventilation models were studied in helmets and one of them is shown in figure 1, which has one groove in the vertical central plane 14mm wide and 7mm deep along with a slot of 48mm x 7mm on the front.

CFD Analysis of Airflow in Helmets

Pinnoji et al [1] investigated the ventilation in motorcycle helmets through experiments and numerical simulations and have shown improvement in air velocities with grooves and slot. Numerical simulations for fluid flow in helmets were carried out here with Computational fluid dynamics (CFD) using FLUENT [2]. Geometry of the head was same as the one used later in impact analysis. The helmet geometry was taken from a commercially available helmet which had a liner foam thickness of 32mm. To simulate the conditions in a wind tunnel the computational domain was chosen 4,750mm long and 600mm high. The upstream and the downstream lengths were 750mm and 4000mm respectively. On account of symmetry of helmet and head with respect to the central plane one half of the domain was modeled.

The inlet velocity of air was taken as 15.7 $m.s^{-1}$ and outflow condition available in FLUENT ™ was used at the outlet. No slip condition was assumed at the walls. Fluid flow was assumed as steady and incompressible. The standard $k-\varepsilon$ model was used as the turbulence model with standard wall functions. Here 'k' is the kinetic energy of the particle and 'ε' is its dissipation rate. Segregated solver, which solves the non-linear equation set sequentially, was used.

Results of CFD Analysis

In the conventional helmet without ventilation, the helmet had regions touching the head where the air velocity is around 1 m.s^{-1} as air could not circulate. Figure 2 shows the velocity contours in central plane of conventional helmet. At the entrance though air has velocity of 9 m.s^{-1} but decreased to around 1 m.s^{-1} in the top region.

Stream lines which show the direction of air flow can be seen in figure 3 when one groove and slot are provided in the helmet. Figure 4 shows the air velocity contours in the central plane of helmet with one groove and one slot. The air velocities in the central plane are improved to 5 m.s^{-1} in the top region compared to around 1 m.s^{-1} in the conventional helmet. Air flow is improved and similar trends are observed for all the ventilated helmet models.

DYNAMICS OF MOTORCYCLE HELMET IMPACT

The motorcycle helmet is made of a shell, liner foam, comfort foam, and strap. Outer shells are made either from a moulded thermoplastic like ABS, polycarbonate or from a composite material with glass or carbon or Kevlar fibers. For Indian road conditions, the IS 4151standard [3] prescribes four impact points for impact tests with one at front, one on the rear and two on the either sides of the helmet and is compatible with ECE R22:03 and SNELL motorcycle helmet standards. It recommends that the peak acceleration of the head should not exceed 300g for an impact velocity of 7m.s^{-1}. The dynamics study consists of two parts. The first part compares the dynamics performance of ventilated and conventional helmet and the second part compares the dynamics behavior of helmet with ABS shell and metal foam shell. Here only front impact results are included.

Finite Element Modeling

A three dimensional finite element model of human head developed by Willinger et al. [4] is used here. The head is considered as rigid for finding peak acceleration and Head Injury Criterion (HIC). The helmet-head drop test with a flat rigid surface was simulated in LS-DYNA [5], which is an explicit FE code for non-linear and dynamic analysis. Mass of the finite element model of head is 4.5kg. The helmet model had 2130 eight node solid elements for outer shell, 7360 eight solid elements for the liner foam, and 858 eight solid elements for the strap. Mass of the helmet was 0.8 Kg with 3mm thick ABS shell. Finite element model of helmet and head is shown in figure 5.

Acrylo-Butadiene Styrene (ABS) shell is considered as elasto-plastic in nature and a material model 3 (*MAT_PLASTIC_KINEMATIC) available in LS-DYNA was used in finite element analysis. Material model 63 (*MAT_CRUSHABLE_FOAM) available in LS-DYNA ™ was used to model the EPS foam. The stress-strain behavior of EPS foam with 44kg.m^{-3} density is taken from Yettram et al. [6].

Metal Foams

Metal foams have low density with high strength and good energy absorption capabilities. Applications in impact-absorbing systems probably offer the greatest potential for metallic foams. Their exceptional ability to absorb large amounts of energy at almost constant pressure suggests applications ranging from automobile bumpers to aircraft crash recorders. Outer shell in motorcycle helmets can be one application for metal foams.

The mechanical behavior of polystyrene foams and metal foams is almost similar. The susceptibility of metal foam, which is aluminum foam here, to undergo gross plastic deformation at an almost constant load with large strains, makes it attractive for absorbing the energy of impact or impulsive loads in packaging and crash applications. In compression after yielding, strains will increase at almost constant stress and once the foam is compressed (or densified) then the stresses will start rising again. Fig. 6 shows the stress-strain behavior of aluminum foam for 300 $kg.m^{-3}$ density [7].

As aluminum foam is a typical filler material, solid elements with 8-node have been used in FE modeling. Material model 154 (*MAT_DESHPANDE_FLECK) was used for modeling metal foam. The yield stress of aluminum foam, which considered here, was 4.41 MPa. The thickness of the outer shell in motorcycle helmets with aluminum foam was 8mm.

Results of Impact Analysis

Comparison of ventilated and conventional helmets

First helmet-head impact behavior was studied for ABS shell helmet with and without ventilation. Figure 7 shows the force versus time curve at $7m.s^{-1}$ impact velocity for head impact with and without ventilation in helmet. The qualitative behavior of force versus time is similar for both helmets. Force on the head with conventional helmet is 9181 N and with ventilated helmet (groove of 14mm x 7mm, slot 48mm x 7mm) 8861 N. It is observed during the helmet impact that the EPS foam deforms towards the groove and slot. EPS foam was not bottomed out in both the helmets at $7m.s^{-1}$ impact velocity. The Head Injury Criterion (HIC) and head acceleration with ventilated ABS helmet are 1368 and 200g respectively.

Comparison of metal foam shell and ABS shell

Similar front impact analysis with helmet-head had been performed with metal foam shell in place of ABS shell. Figure 8 shows the force versus time curve at $7m.s^{-1}$ impact velocity with ABS and metal foam shell helmets. Force of 9181 N was observed on the head with ABS helmet and 8872 N with metal foam helmet. Acceleration versus time at the centre of gravity of the rigid head for both ABS and metal foam shell helmets is shown in Fig. 9.

The magnitude of the acceleration for both ABS and metal foam shell helmets is same which is 197g. The values of HIC are 1473 and 1418 for ABS and metal foam shell helmets respectively.

CONCLUSIONS

Ventilation in motorcycle helmets is studied. Air velocities inside the conventional helmet are very low but improved when one groove and slot are provided. Impact dynamics studies are carried out with conventional and ventilated helmets. The provision of groove and slot didn't affect the dynamic performance of the helmet. The impact behavior of a much lighter metal foam helmet is also studied and its performance is comparable to ABS helmet in terms of HIC, forces, and acceleration.

ACKNOWLEDGEMENT

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FIGURES

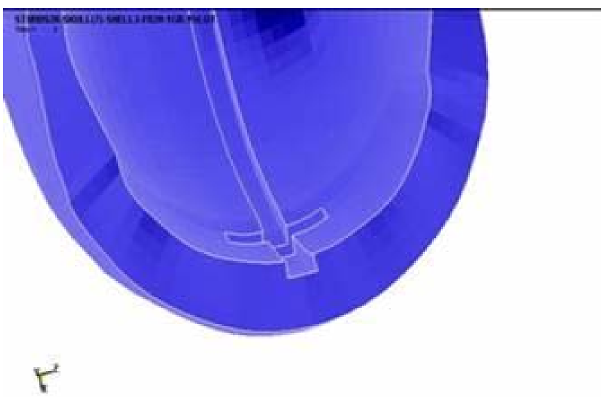

Fig 1: 14mm x 7mm groove with slot in helmet

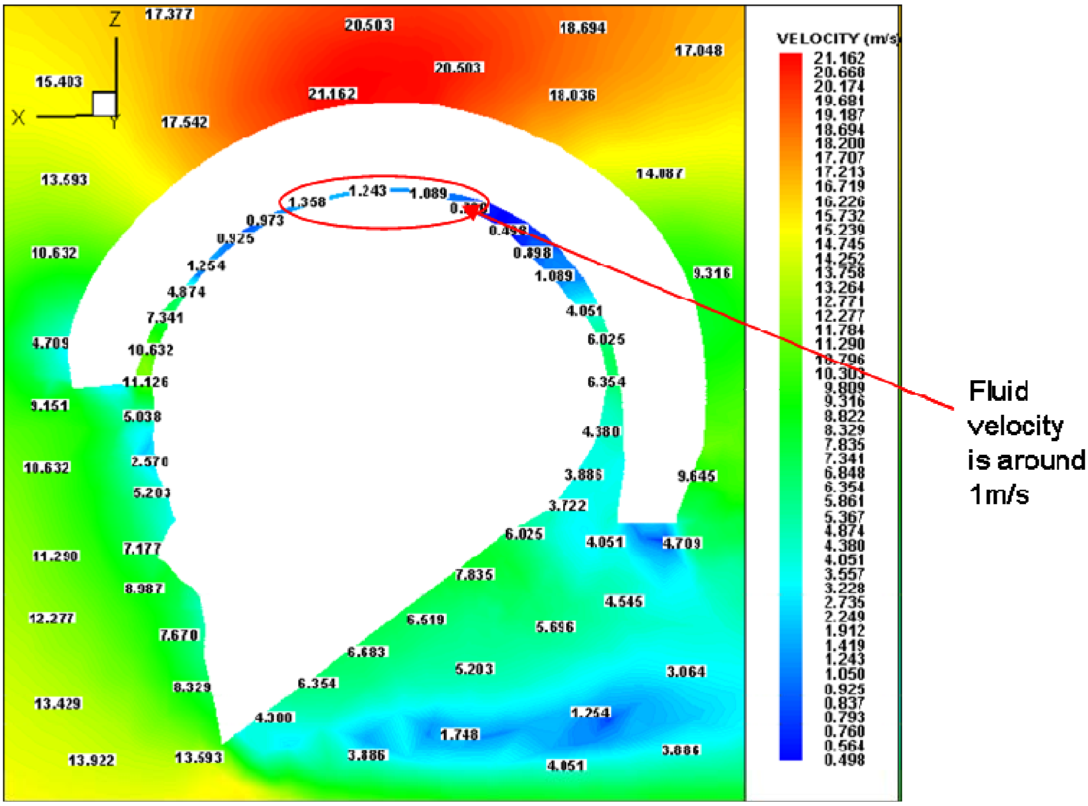

Fig 2: Velocity Contour values on the central x-z plane within and outside the gap of a helmet without ventilation.

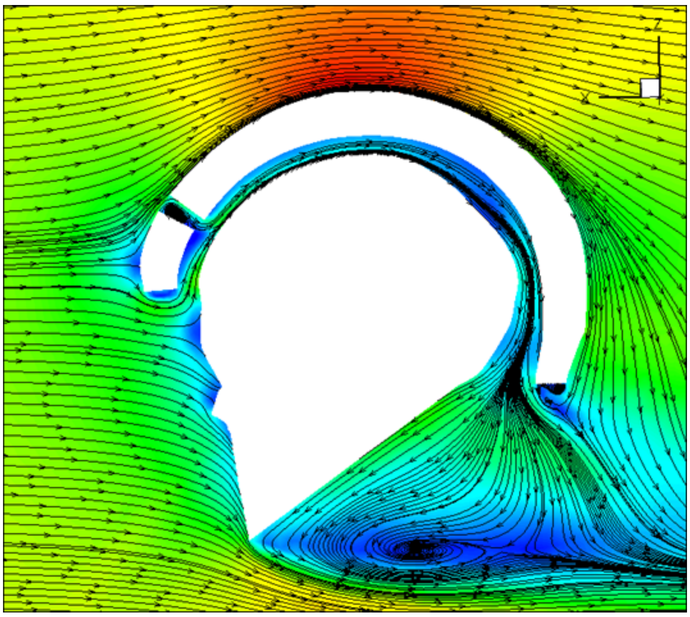

Fig 3: Streamlines in and outside the gap on the central x-z plane in helmet with 14mm x 7mm groove and 48mm x 7mm slot.

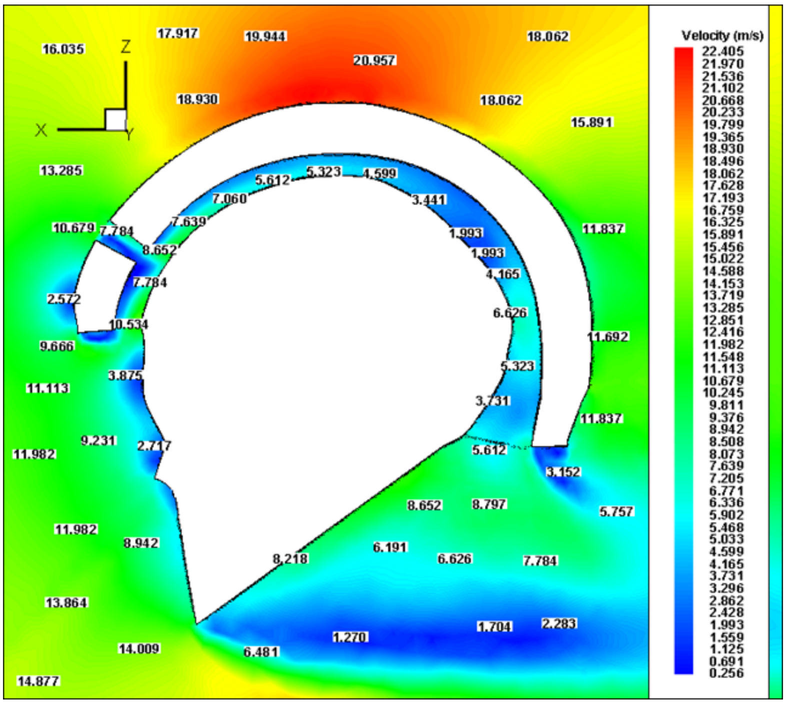

Fig 4: Velocity contour values on the central x-z plane in and outside the gap with 14mm x 7mm groove and 48mm x 7mm slot

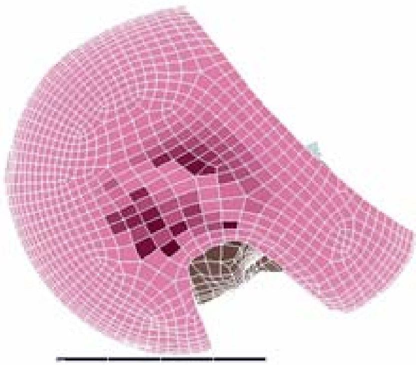

Fig 5: Finite element model of helmet-head in front impact

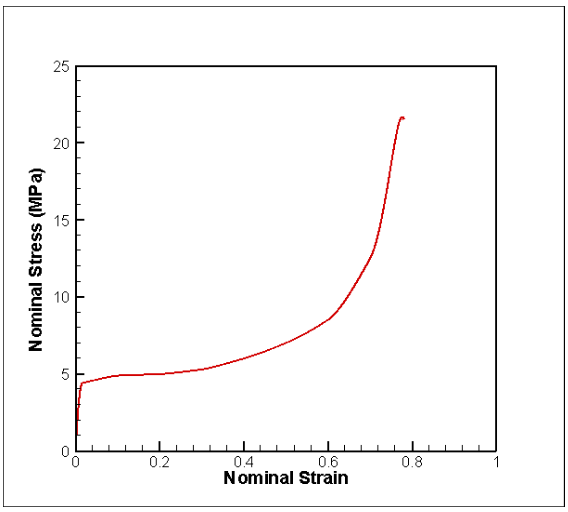

Fig 6: Stress-strain relation for Aluminum foam of 300 kg.m^{-3} density

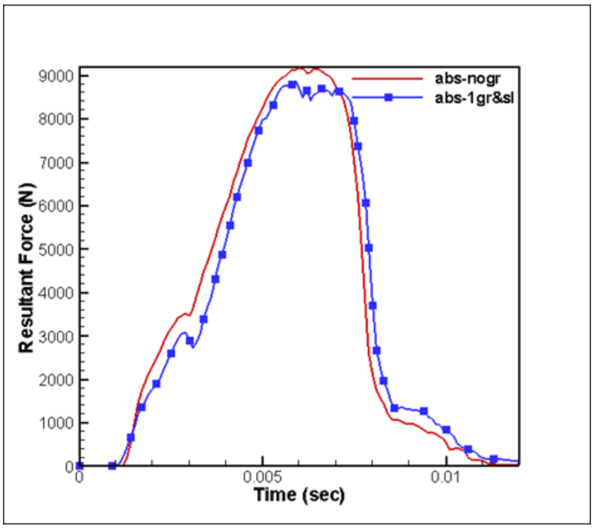

Fig 7: Total force on the head with and without ventilation in helmet

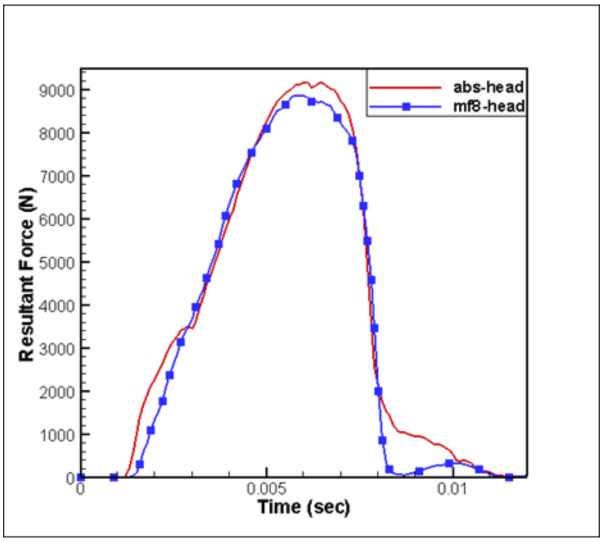

Fig 8: Total force on the head with helmets of ABS shell and Metal foam shell

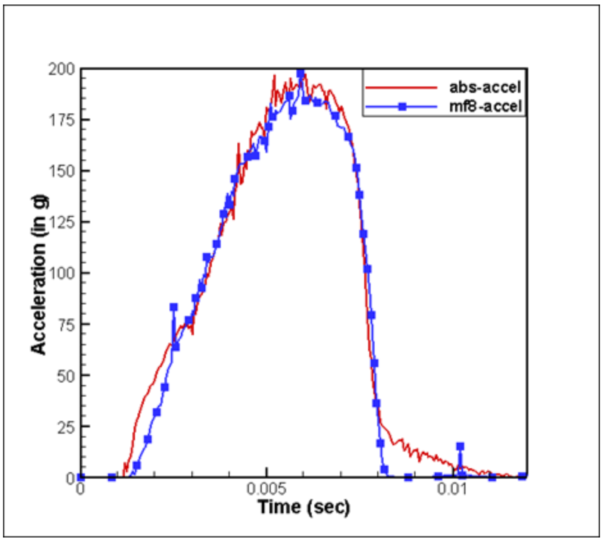

Fig 9: Acceleration in ‘g’ of the head with helmets of ABS shell and Metal foam shell