NEW MOTORCYCLE HELEMTS WITH METAL FOAM SHELL

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ABSTRACT

New motorcycle helmets are designed with metal foam shell and their impact behaviour has been studied. Impact experiments have been performed on a first set of prototype helmets with metal foam shell at standard impact locations. Numerical simulations are performed and the predicted headform acceleration is validated with experimental data. The biomechanical characteristics of head impact were studied with both metal foam and ABS helmets. The helmet with metal foam shell performed reasonably well compared to ABS helmet.

Keywords: Helmets, Metal foam shell, Biomechanics, Impact tests, Finite elements

Motorcycle crash helmets absorb the shock and cushion the human head so that the time of actual impact is extended. They spread the impact over large area of the human head thereby decreasing the pressure at any one point. The outer shell in regular helmets is made of thermoplastic (either ABS or Polycarbonate) which is heavy and stiff. The outer shell spreads the impact over large area of the helmet and prevents the penetration of sharp objects. To make more comfortable for a rider it is desirable to reduce its weight. One way of doing this is using an outer shell of lighter material without compromising on its dynamic performance and safety.

One group of materials, which reduce weight and absorb energy, is the porous materials. Metal foams are a class of cellular materials and have many interesting properties such as high stiffness in conjunction with low specific weight combined with good energy absorption characteristics. These unique characteristics make them useful for applications range from automobile bumpers to aircraft crash recorders. Outer shell in motorcycle helmets can be one such application for metal foams, which needs to be studied. In a helmet besides the energy absorbed by the polymer foam, metal foams can also absorb energy because of their porous nature and can prevent the penetration of sharp objects. Metal foams based on aluminium or nickel are the most commonly used at present in various applications.

METAL FOAMS

A general overview over the mechanical properties of cellular materials can be found in Gibson and Ashby [1]. The stress-strain curve of polystyrene foams (like EPS) and metal foams have similar shapes although their yield points are very different. 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. For solid metals with isotropic mechanical behaviour, the von Mises yield criterion is widely used and the yield surface is independent of hydrostatic stress. It is assumed that the elastic volumetric energy does not affect the plastic flow of metals. Metal foams exhibit plastic flow for a pure hydrostatic stress condition. It follows that the elastic volumetric energy affects the plastic flow of foams and it is necessary to extend the yield criterion to take this effect into account. Several studies were made to investigate the constitutive response of aluminum foams in the recent past. Deshpande and Fleck [2] studied the isotropic and continuum based metal foams and included a hydrostatic stress term in the yield function to take into account the volume changes in the foam. Figure 1 shows the stress-strain behaviour of aluminium foam for 500 $kg.m^{-3}$ density. Hanssen et al [4] established an extensive experimental database for the structural behaviour of aluminium foam-filled extrusions. They discussed and compared various material models for aluminium foam. Hanssen et al [5] carried out experimental bird strike tests on aluminium foam based double sandwich panels. They predicted the failure of structural components with aluminium foam in bird-strike events through a numerical model.

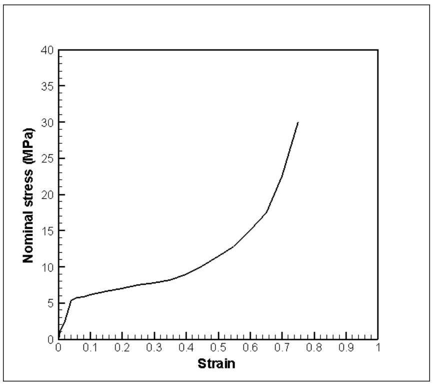
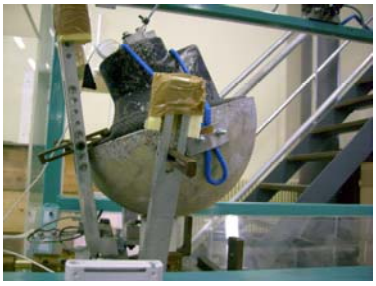


Fig 1. Stress-strain behaviour of Aluminium foam with 500 kg.m^{-3} density (Alulight [3])

IMPACT EXPERIMENTS

Metal foam shells were manufactured by ALULIGHT International GmbH, Austria and EPS foams by ALTA Pack Pvt. Ltd., India. Only prototype helmets are considered for impact studies as it's the first time for making helmet metal foam shells. The thickness of the outer shell in motorcycle helmets with aluminum foam was 8mm. The EPS liner foam is of 30mm thick with 45kg.m^{-3} density.



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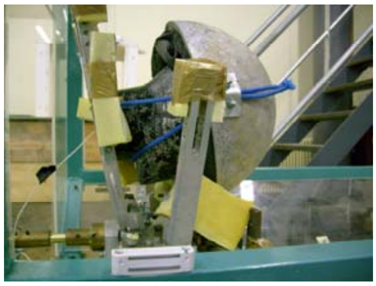

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Fig 2. Testing with Metal foam shell helmets a. Front impact b. Top impact

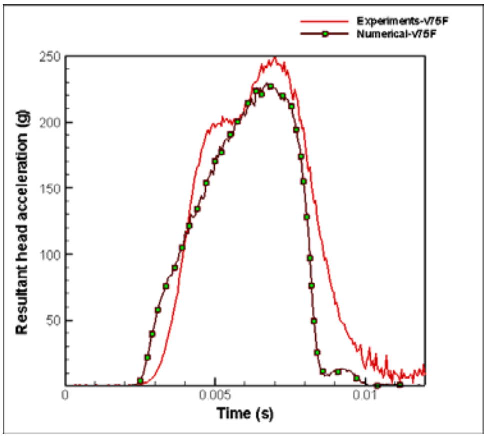
Standard ISO headform and standard impact conditions were considered in tests. Impact tests were performed at helmet front (B point) and vertex (P point) points. Tests were performed at the Impact laboratory of IMFS-ULP in Strasbourg, France. The experiment results reported here are at 7.5 m.s^{-1} velocity for both front and vertex impacts. Total 16 tests were performed. Linear acceleration of the headform was recorded for the computation of HIC. Alulight International GmbH had conducted the compression tests on Aluminium foam specimen and supplied the material property data. The yield stress of aluminium foam, which is considered here, is 7.5 MPa.

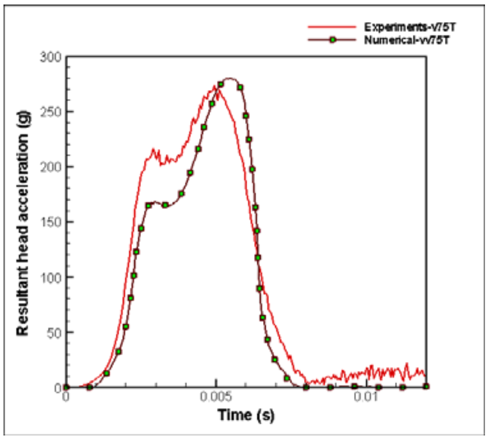
FINITE ELEMENT ANALYSIS OF HELMET IMPACT WITH METAL FOAM SHELL

Validation with Experiments

A numerical model of this problem is developed with the non-linear, finite element code LS-DYNA [6]. The geometry of Aluminium foam helmet in experiments and finite element analysis (FEA) is same. As aluminium foam is a typical filler material, solid elements with 8-node have been used in FE modeling. Metal foam was represented by material model 154 of LS-DYNA (*MAT_DESHPANDE_FLECK). Material model 3 (*MAT_PLASTIC_KINEMATIC) and Material model 63 (*MAT_CRUSHABLE_FOAM) were used for ABS shell and EPS liner foam respectively. Deformable head is considered while investigating the impact forces on the head and head is assumed as rigid for peak acceleration and HIC.

The metal foam shell had undergone permanent plastic deformation and flattened in the impact region which was also observed in experiments. A comparison of acceleration at the centre of gravity of head between the predicted and experiments is shown in figure 3. For front impact the prediction was good albeit there was some qualitative difference in the head acceleration traces during the initial stage of impact. For top impact the prediction was better.





(a) Front impact (b) Top impact

Fig 3. Headform acceleration traces with Meta foam helmet at 7.5 $m.s^{-1}$ velocity: Predicted vs Experimental

The rise in headform acceleration both in experiments and in FEA starts at the same time. It can be observed from figure 3a that the predicted value of headform acceleration from the numerical simulations for front impact at 7.5 $m.s^{-1}$ velocity is 230 g where as from the experiments it is 248 g approximately. For top impact at 7.5 $m.s^{-1}$ velocity the predicted headform acceleration from numerical studies qualitatively matched with experiments but again peak values are different and can be seen in figure 3b. The deviation in peak acceleration was 9% in front impact and 3% in top impact.

Dynamics with Full-face Helmets

Next similar impact studies were carried out with full face helmets of ABS shell and metal foam shell through finite element analysis. The dynamic performance of helmet with ABS shell at 7.5 $m.s^{-1}$ velocity is validated for headform acceleration. Figure 4 shows the traces of headform acceleration with ABS helmet and the Aluminium foam helmet for a frontal impact at 7.5 $m.s^{-1}$ velocity. The peak acceleration, HIC, and impact duration are almost same with both helmets. ULP head model [7] is used for evaluating the impact forces on the head. Figure 5 shows the traces of resultant force on the head for front and top impacts at 7.5 $m.s^{-1}$ velocity. It is observed that there is a reduction of 160 N force on the head for a front impact (figure 5a) and 1190 N for a top impact (figure 5b).

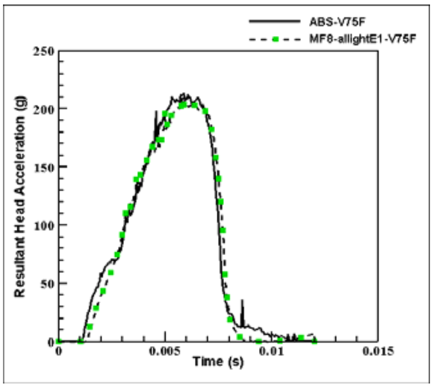
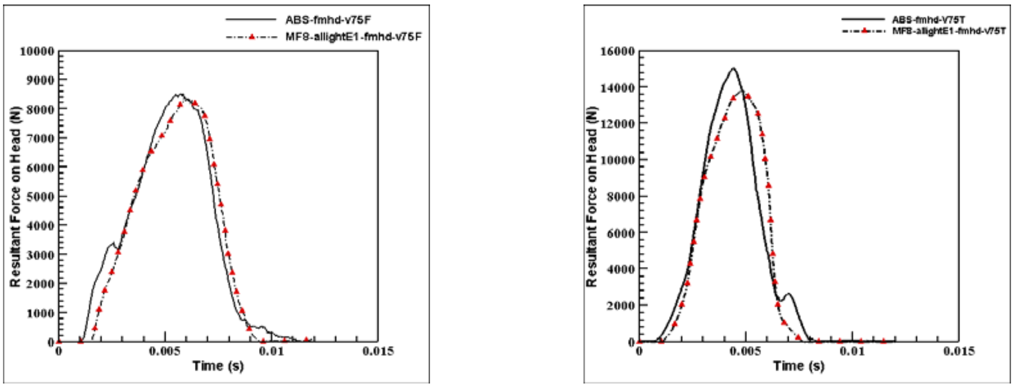


Fig 4. Headform acceleration traces for a frontal impact at 7.5 $m.s^{-1}$ velocity with full face helmet: ABS vs Metal foam shell

The density of metal foam shell which was used in experiments is 500 $kg.\ m^{-3}$ and is quite high. The mechanical properties of foam depend on the density. There is approx. 30% reduction in mass with the present metal foam shell of 8mm thick compared to ABS shell. The mass would further come down if lower density metal foams are used. FE simulations were carried out to investigate the mechanical behaviour of metal foam helmets when the density was reduced to 300 $kg.\ m^{-3}$ and the properties are referred from Hanssen et al [4]. The biomechanical characteristics in front impact at 7.5 m.s^{-1} velocity are compared in table 1. The mass of outer shell is reduced by 57% with this metal foam and the values of HIC and force on the head are also low.



a b

Fig 5. Forces on the Head with full-face helmet at 7.5 m.s^{-1} velocity a. Front impact b. Top impact

Table 1: Front impact at 7.5 m.s^{-1} velocity with full face helmet

Outer shell	Mass (kg)	With Rigid headform		With deformable head
		Peak Acceleration (in g)	HIC	Force on the Head (N)
ABS	1.171	213	1762	8504
Metal foam - Alulight	0.829	210	1773	8344
Metalfoam –Hanssen [4]	0.497	200	1685	8300

CONCLUSIONS

New motorcycle helmets with metal foam shell are designed and developed. Impact experiments are carried out on prototype metal foam helmets at different impact locations. The numerical model of the metal foam helmet is validated by experiments. The metal foam is deformed at the impact region and shape of the geometry is changed i.e. becomes flat locally after impact. The permanent deformation of the metal foam with one impact is its draw back. It can be used only for one impact. The dynamic performance of full face helmets with metal foam shell is investigated by finite element modeling. It is observed that the resultant force on head is less with metal foam helmet as compared to ABS helmet. The helmet weight is reduced by 30 % with the present metal foam helmet (500 kg.m^{-3}) than the conventional ABS helmet. Further studies are required at higher impact velocities for successful use of metal foam shell helmets.

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