MODELING AND STRESS ANALYSIS OF HUMAN HEAD IN FRONTAL IMPACT WITH A DEFORMABLE BODY, USING FEM METHOD

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Abstract: This study investigates the effect of materials for their impact absorbing qualities and behavior under impact by using LS-DYNA finite element codes, in order to distinguish suitable materials for the car interior structure. This biomechanical study was performed by applying a visco-elastic model for the human head for the 50th percentile male population colliding with a constant velocity of 6.5 m/sec (15mph) to a barrier in the situation of frontal impact. Aluminum, ABS, Alulight, Alporas and Expanded PolyPropylene[1] (EPP31) which are used in car industry have been selected to perform the analysis. Results show that the maximum stress, maximum strain and peak head deceleration are directly related to material density, yielding strength and elasticity. Alporas foam with the lowest yielding strength exerts minimum stress (2.3Mpa), strain (0.000134) and also minimum peak deceleration (299g) to the head while Aluminum with the maximum yield strength and density provides the highest values (60 times). According to related safety standards, the exerted values due to Alporas are in a safe range and point out the energy absorbing capability of Alporas in contrast to the other selected materials while Alulight, EPP31 and ABS are in the next ranks, respectively.

Introduction

Head and brain injuries are the major concern which mainly result from motor vehicle crashes and are a leading cause of death. In spite of occupant death, observations mostly showed that wound region comes through crash is very small. This phenomenon is an exertion of large momentum at a few milliseconds which is generated during head impact with automobile interior. Whereas this study investigates the effects of materials for their impact absorbing qualities and their behavior under impact and stress generated by them on human head during collision, the attempt was to investigate materials which are used in automobile interior such as foams and energy absorbing materials. Automobile A-pillar is one of nearest interior body to driver and his/her adjacent occupant. Generally A-pillar is a hollow cross sectional steel/aluminum profile which is trimmed with cellular materials such as polymeric foams or some appropriate metals. So this study analyzes aluminum, alporas, alulight, EPP and ABS effects on human head by means of LS-DYNA codes.

Materials and Methods

The purpose of energy absorbing systems is to protect a specified object from damaging acceleration or deceleration. The damage tolerance of an object is measured by the greatest acceleration or deceleration it can withstand without harm. Acceleration is measured in units of "g", the acceleration due to gravity.

Ideal energy absorbers have a long, flat stress-strain curve. Like that of Fig. 1: the absorber collapses plastically at a constant stress called the plateau stress, σ_{pl} , and absorbs the impact energy.

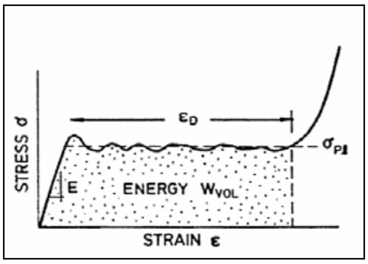

Figure 1: A stress curve for an energy absorber [1]

Energy absorbers for packaging and protection are chosen so that the plateau stress is just below that which will cause damage to the packaged object, the most desirable stress-strain curve is then the one that has the longest plateau and therefore, absorbs the most energy [1]. Solid sections do not perform well in this role. Hollow tubes, shells and metal honey-combs loaded parallel to the axis of the hexagonal cells have the right sort of stress-strain curves, and so do metal foams. To protect fully, the package-material must absorb all the kinetic energy of the object, bringing it to rest without the deceleration exceeding the limiting g-factor.

The kinetic energy KE depends on the mass m and the velocity v of the object as expressed by equation 1:

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[1] -Expanded Poly Propylene with a density of 31 kg/m^3

$$KE = \frac{1}{2} m v^2 \qquad (1)$$

Knowing about material properties of the human head, this is important that biological materials do not follow the constitutive relations for common engineering materials. A biological material is often anisotropic, inhomogeneous, nonlinear and visco-elastic. In addition, there is a great variability between different individuals [2]. On the other hand the geometry of human head depends extensively on the age. Head bones and tissues properties vary through growth especially during infancy. These differences in proportion result in head inertial characteristics that vary with age. Also bones and tissues properties of head vary by location on the head. So modeling of human head is done based on some identified percentile of each community or by CT-image of individuals. The geometry of skull was considered as a simple semispherical shell and its property varies from simple elastic material to visco-elastic one. To perform the analysis, this study uses a 50th percentile of male with an overall head dimensions of 195 mm length, 155 mm width and the weight of 4.44 kg as illustrated in figure 2. The material of skull is considered visco-elastic and its stress relaxation behavior is considered as equation 2 [3]:

$$G(t) = G_\infty + (G_0 - G_\infty) e^{-\beta t} \qquad (2)$$

Where β is the decay constant and equals to $1591 s^{-1}$. The other constants are listed in table 1.

Table 1: Mechanical Properties of Human Skull

Bulk modulus	Short time shear modulus	Infinite time shear modulus	Thickness	Elasticity modulus
$K = 3.32 GPa$	$G_0 = 8.2 GPa$	$G_\infty = 2.29 GPa$	$t = 3 mm$	$E = 5.58 GP$

In order to model a barrier, a generalized 4 mm thickness A-pillar of hollow section is considered while it was fixed at its two ends as in automobile interior assembly, refer to figure 2. Different barrier materials which are considered to evaluate their effects on the impactor (human head) are aluminum, alporas, alulight, expanded poly propylene and ABS. The analysis was performed by powerful FEM codes, LS-DYNA and ANSYS/LS-DYNA as automatic contact surfaces regime. The head velocity was considered 15 mph as standard impact velocity where head collides to barrier in sagittal plane in the situation of frontal impact with the angle of 45 degrees with respects to the horizontal plane. Analysis was performed with 3912 elements and 3945 nodes while each analysis run lasted about 20 hours to be completed [4].

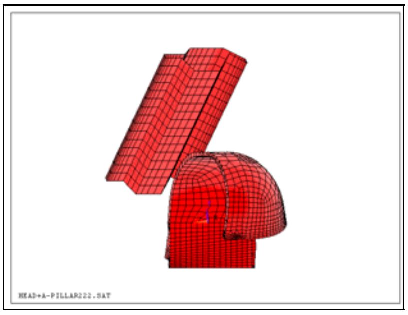

Figure 2: FE model of human head and A-pillar as a barrier

Results

The maximum values of each set of the analyses are listed in table 2.

Table 1:The maximum values obtained from the analyses

barrier **Value**	Aluminum	ABS	EPP31	Alulight	alporas
Max. Stress (MPa)	120.6	31.2	19.6	14.9	2.3
Max. Strain $\times 10^{-3}$	8.9	2.6	1.7	1.2	0.134
Deceleration (g)	5466	2152	931	1278	299

Contact area location on the head was the same during impact with the aluminum, ABS and EPP31 barriers while it varied when head collided with alporas and alulight barriers as illustrated in figure 3. Aluminum and ABS exerted maximum stresses on the head unlike alporas and alulight and also EPP31, the stress generated due to alporas was in a safe range. No rebound velocity was occurred from alulight to head while the rebound velocity in the case of aluminum was too high. This can be quite dangerous for the head and may cause whiplash injury. It was observed that the head deceleration due to alporas was in a safer range in contrast to the other selected materials. The contact duration in the case of alporas found to be the maximum while it had the smallest value when the head collided with an aluminum barrier.

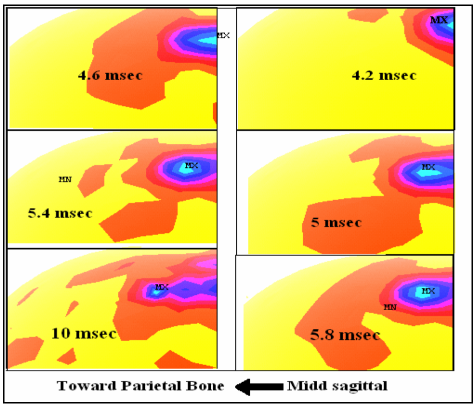

Figure 3: Displacement of maximum stress area during impact in the case of alulight and alporas barriers

Head deceleration on the first five milliseconds of contact is shown in figure 4.

According to figure 4, alporas exerts the minimum deceleration to the head while aluminum exerts the maximum. The same conclusion is reached when we consider the stress and strain on figures 5, 6.

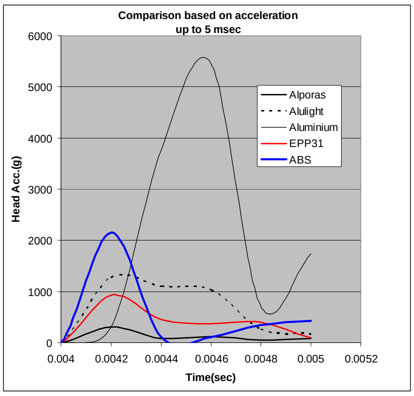

Figure 4: Head deceleration comparison during impact

The foregoing figures show that alporas can absorb contact energy more than the other selected materials, therefore head sustains lower impact stress and strain. This is expected to cause a rebound velocity of head. Figure 7 confirms this phenomenon. When head collides on barriers, the aluminum exerts maximum rebound velocity rate while alporas exerts no rebound velocity, and steadily collapses during impact plastically.

The forgoing figures illustrate that aluminum barrier has the shortest duration of contact time while alporas has the longest as Snyder observed for rigid and deformable barriers, respectively.

Alulight and alporas stress-strain curves which were obtained from the analysis are represented in figures 8 and 9.

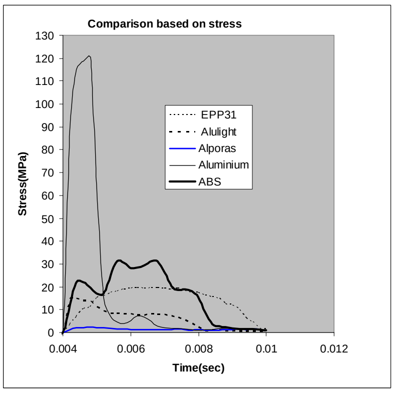

Figure 5: Stress comparison on frontal bone according to each barrier

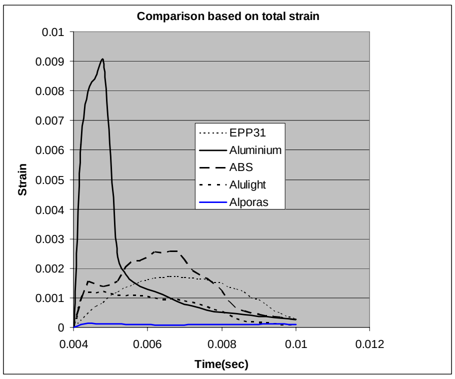

Figure 6: Strain comparison on frontal bone according to each barrier

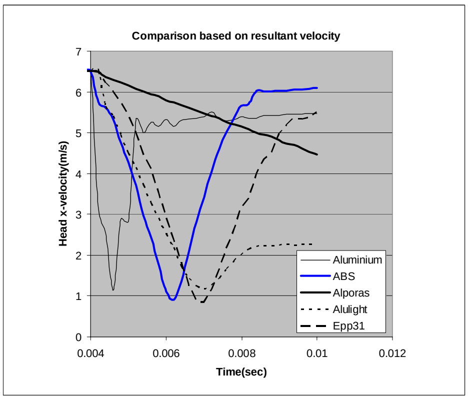

Figure 7: Rebound velocity of head based on each barrier

It can be observed that these materials are capable of absorbing a large amount of impact energy and have longer plateau especially the alporas barrier.

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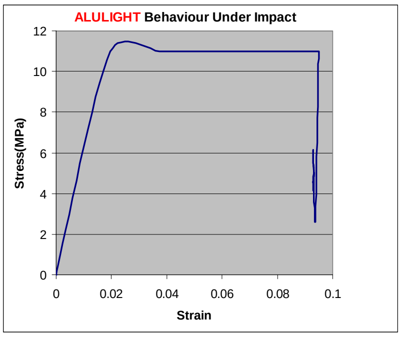

Figure 8: Alulight behavior under impact

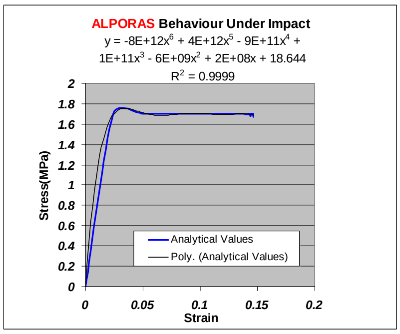

Figure 9: Alporas behavior under impact

5. Conclusions

Results show that alporas, alulight and EPP31 are capable of absorbing impact energy. Among those, alporas has the longest plateau and exerts minimum stress on the head. The study demonstrated that exerted stress, strain, and deceleration depend directly on the barrier behavior. Therefore, for a given material lower stress will be exerted for less density. The elasticity and yield strength have the results illustrated in figures 10 to 12.

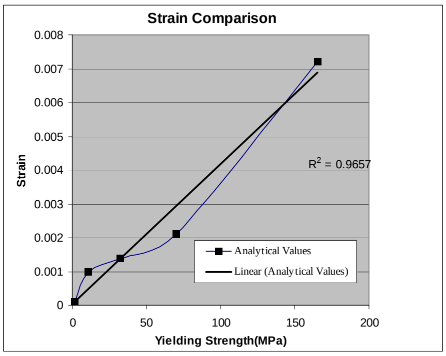

Figure 10: Yield Strength Effect on Exerted Strain

As it was expected, alporas has the minimum yield strength and exerts the lowest stress, deceleration and strain to the head, and their values are in the safe range. That is because alporas barrier absorbs approximately all of the impact energy. This barrier caused no whiplash to the body and head sustained no accelerated rebound velocity. Alulight and EPP31 which absorb the majority of impacted energy are in the later ranking.

According to the analysis and in the absence of economical aspects, the alporas foam which can be used in car interior is the best candidate to absorb impact energy. Additionally, it is a good heat and humidity resistant. The EPP31 and alulight foam are in the next ranking.

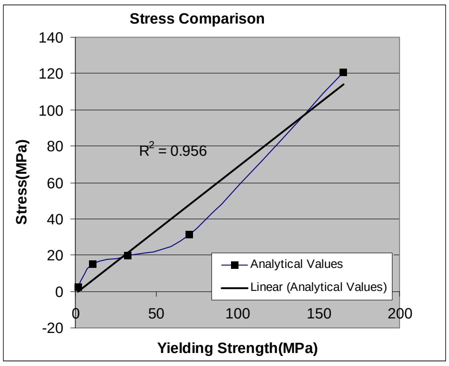

Figure 11: Yield Strength Effect on Exerted Stress

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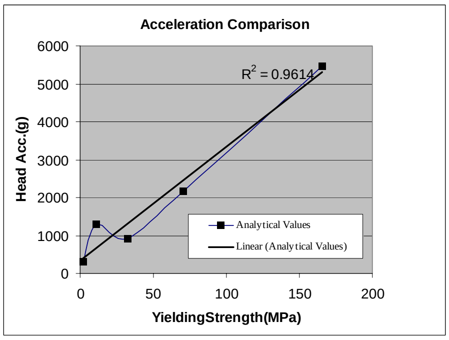

Figure 12: Yield Strength Effect on Exerted Deceleration

6. References

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