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THE EFFECT OF AUTOMOTIVE SIDE MEMBER FILLING ON CAR FRONTAL IMPACT PERFORMANCE

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ABSTRACT

To achieve lightweight design while retaining its crash performance, an aluminum alloy component filled with foam has been adopted as an alternative lightweight material. In the paper, the effect of different types of filling on the automotive side member is studied. Impact performance is compared in terms of the automobile energy absorbing capability and also its occupant safety, measured in terms of head injury criteria (Manning) and chest severity index (CSI). It is shown that the partially filled side member with values of 513.6 (HIC15), 677.3 (HIC36), 807.2 (CSI) and a weight of 5.45kg is found to yield lower potential of injury, and higher specific energy absorption (SEA) compared to an empty side member. It can be concluded that, even though the fully filled side member shows remarkable performance in terms of HIC, it increases the chances of injury to the chest. Future study can include different types of foam for performance improvement.

***Keywords*:** Impact; HIC; CSI; SEA.

INTRODUCTION

The recent trend in automobile design is aimed at improving crash safety and environmental-friendliness. For the former, energy absorbing members have to absorb sufficient collision energy, whereas for the latter, the automobile structure must be lightweight in order to improve fuel efficiency and reduce tail gas emissions. According to Koffler and Rohde-Brandenburger (2010) a decrease in a vehicle's weight of 100 kg was estimated to reduce the need for 0.12 liters of diesel. A decrease in automobile weight is achievable by the use of alternative materials and construction measures. However, a change in the material used usually requires changes to the component design as well. Figure 1 illustrates the effect of increased requirements of automobile performance on automobile weight. Clearly, additional equipment for comfort and safety features overcompensates for the weight advantages realized by lightweight design. Measures for improving comfort, safety and universality require a more powerful engine in order to maintain or even improve the road performance of an automobile in spite of an increase in weight.

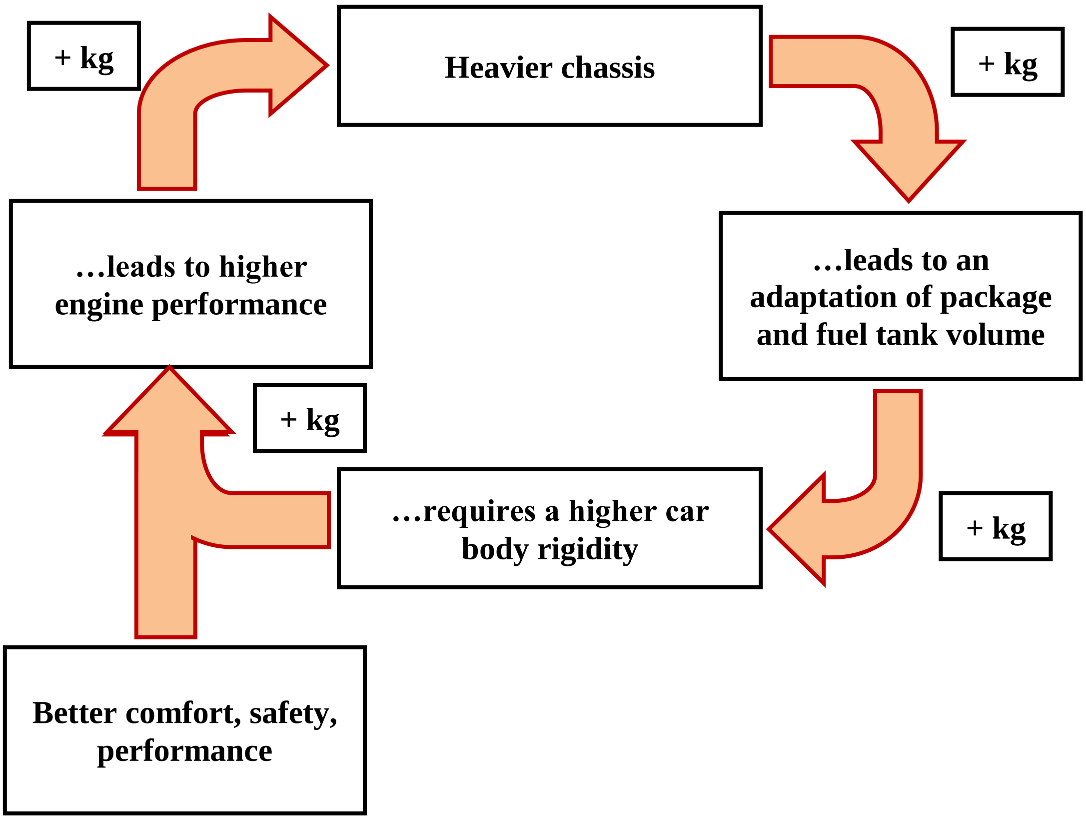


Figure 1. Weight spiral (Carle & Blount, 1999).

Steel has been extensively used in the automotive industry because of its special properties. Steel as an automobile body material is typically known to be inexpensive material, easy to form, consistent in supply, with corrosion resistance through zinc coatings, easy to join, recyclable and with good crash energy absorption (Adekunle, Adebiyi, & Durowoju, 2013; Davies, 2003). New materials are considered for incorporation into automobile designs if they provide benefits at an affordable cost. Various lightweight materials have been used in the automotive industry, for instance aluminum alloys, magnesium alloy and composite materials. It has been established that an aluminum body is lighter than a steel body for constant stiffness. The characteristic properties of aluminum, high strength stiffness to weight ratio, good formability, good energy absorbing ability, make it the ideal candidate to replace heavier materials (such as steel) in the car (Miller et al., 2000). A foam-filled structure can be considered a mixture of constructive and material lightweight design. Foam exhibits a combination of low weight and energy absorption ability (Nemat-Nasser et al., 2007). Compared to honeycomb, foam presents quasi-isotropic mechanical properties and is cheaper. Metallic foam is usually used in automotive components as a foam-metal sandwich layer or as a tube filler. As a filler, metallic foam has improved bending resistance and energy absorption (Srinath et al., 2010). Lightweight components with high energy absorbing ability add positive values to an automobile's performance. The use of alternative materials such as aluminum and aluminum foam offer an option for improved weight-specific energy absorption properties than does conventional mild steel. In a frontal collision, the impact load is transmitted first through the bumper, then through the side members and many other surrounding parts, before finally going to the passenger compartment, so, it is desirable to absorb as much kinetic energy as possible before it is passed to the passengers. This study performs a numerical analysis of automotive side members that gives a crucial understanding about managing energy transferred for occupant safety during a collision under predicted frontal impact conditions.

THEORY

In the light of structure efficiencies, an automotive energy absorbing structure is expected to absorbed more energy with the least possible weight. Thus, specific energy absorption (SEA) is introduced as (Taher et al., 2009):

$$SEA = \frac{E_a}{m} \tag{1}$$

where it is the energy per unit mass.

An important measure of occupant injury as a result of mechanical impact, used by automobile and other industries, is the Chest Severity Index (CSI) and Head Injury Criteria (Manning). The value of HIC can be obtained using the Equation (3.5) (Gong, Lee, & Lu, 2008). The magnitude of linear acceleration observed at the center of the head upon impact is denoted by *a(t)*.

$$\mathrm{HIC} = \max\left[\left(\frac{1}{t_2 - t_1}\int_{t_1}^{t_2} a(t)\,\mathrm{d}t\right)^{2.5}(t_2 - t_1)\right] \tag{2}$$

t_1 and t_2 also denote the two time points in the resultant acceleration of duration T, such that $0 \leq t_1 < t_2 \leq T$. The values of t_1 and t_2 are obtained so as to maximize Eq. (3). Thus, HIC is an acceleration-based value and is obtained from the time versus acceleration pulse. A dummy equivalent of HIC value, denoted by HIC(d), is given as (Deb, Gupta, Biswas, & Mahendrakumar, 2005):

$$\mathrm{HIC}(d) = 166.4 + 0.75446 \text{ x HIC} \tag{3}$$

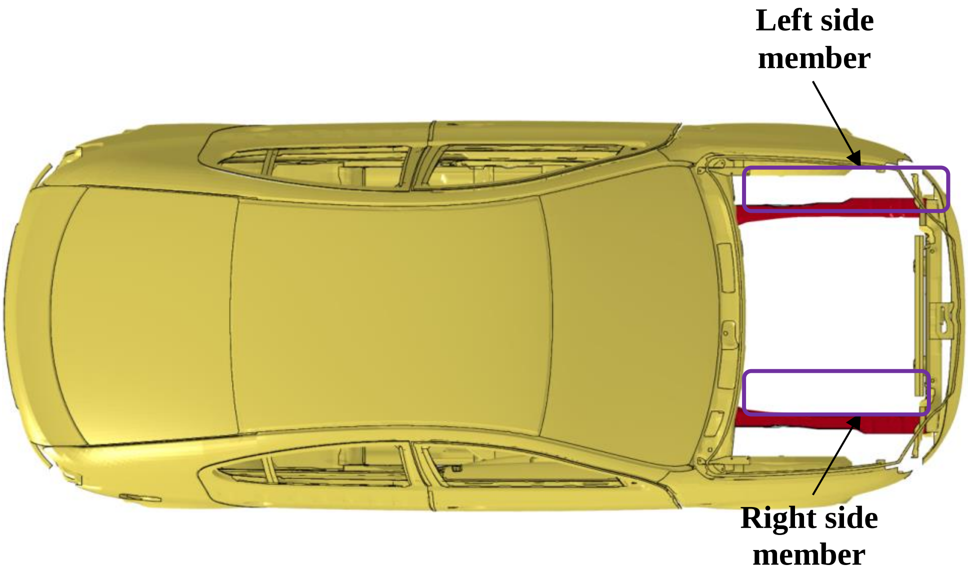
METHODOLOGY

In this study, crash simulation is carried out using commercial finite element software LS-DYNA. In the dynamic simulation, the car impacts a rigid wall at a velocity of 48km/hr as prescribed in Federal Motor Vehicle Safety Standard (FMVSS) No. 208. Figure 2 shows the LS-DYNA car model and side member component created from the CAD data.

The aluminum alloy used in this study is AA6060, temper T4. Table 1 summarizes the mechanical properties of AA6060 T4. The important properties are the density, ρ; Young's modulus, E; Poisson ratio, ν; yield stress, $\boldsymbol{\sigma_y}$; ultimate tensile stress, $\boldsymbol{\sigma_u}$ and fracture strain, ε_f. Table 2 provides general stress-strain relationship for arbitrary foam density that is used for the modeling of aluminum foam. The density of the aluminum foam used in this study is 0.2kg/m^3.

Table 1. Mechanical properties of AA6060 T4 (Reyes, Langseth, & Hopperstad, 2002)

Material	ρ (kg/m^3)	E (N/mm^2)	ν	σ_y (N/mm^2)	σ_u (N/mm^2)	ε_f
AA6060	2700	66820	0.28	91	175	0.22



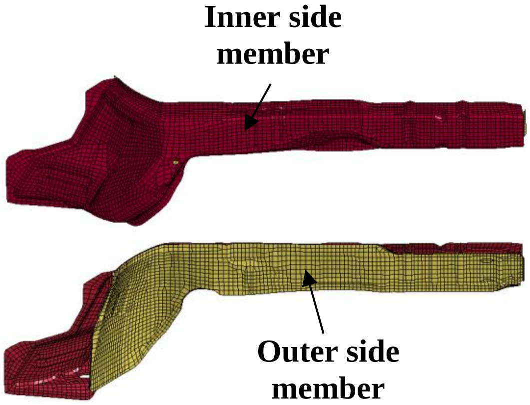


Figure 3. Car and component model (Courtesy of PROTON)

Table 2 Stress-strain relationship for arbitrary foam density (Hou, Li, Long, Yang, & Li, 2009)

Strain	0	σ_p/E	0.6	0.75	0.8
Stress	0	σ_p	σ_p	1.35 σ_p	0.05E

RESULTS AND DISCUSSION

The simulation was carried out for a complete car. Occupant crash protection was assessed using the injury criterion The common criteria for evaluating potential injury during a car collision are the Head Injury Criteria (Manning) and Chest Severity Index (CSI). These purport to identify the level that could be tolerated without permanent damage being incurred in a normal healthy adult. Figure 4 shows the variation of acceleration with time of a node on dummy that is used to calculate HIC15 for empty, fully filled and partially filled side member. The calculation of HIC is taken at the area that will maximize the value of the acceleration. It can be seen from Figure 5.1 that the acceleration of the node associated with the empty (E), fully filled (Ff) and partially filled side member (Verjedo) is almost identical before 0.06s. The acceleration however stays comparatively low for the fully filled (Ff) side member after 0.06s. As a result, the HIC15 reading of Ff is very low, at 297.2.

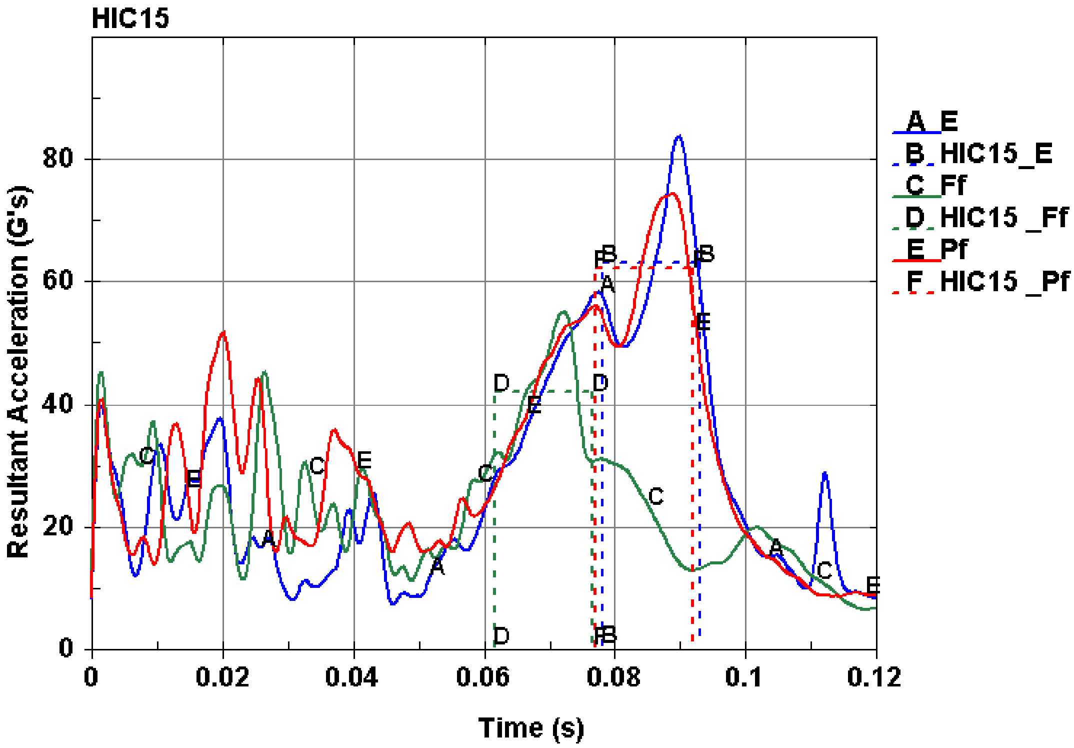


Figure 4. HIC 15 of empty, fully filled and partially filled side member

Figure 5 shows the acceleration versus time of a node on dummy that is used to calculate HIC36. The calculation of HIC36 uses the same acceleration curve as in Figure 4. The difference lies in the fact that HIC36 is calculated for 36ms time duration, instead of 15ms as is the case for HIC15. Once more, the HIC36 reading of Ff is the lowest, at 331.7.

In the meantime, Figure 6 shows the acceleration versus time of a node on dummy that is used to calculate CSI for an empty, fully filled and partially filled side member. The calculation of CSI is done in 3ms duration. Generally, it can be seen from Figure 6 that the acceleration is almost identical for the empty, fully filled and partially filled side members, except for the time interval 0.01 to 0.02s, where the Pf does not exhibit the same sudden change in acceleration as the E and Ff node. Although the HIC reading for Ff is the lowest, it yields the highest value for CSI, at 1116.0. Furthermore, the peak acceleration exhibited by E and Ff is very high, exceeding 60g. On the other hand, Pf acceleration is found to be lower than 60 g. (‘g’ in this case is the gravity acceleration).

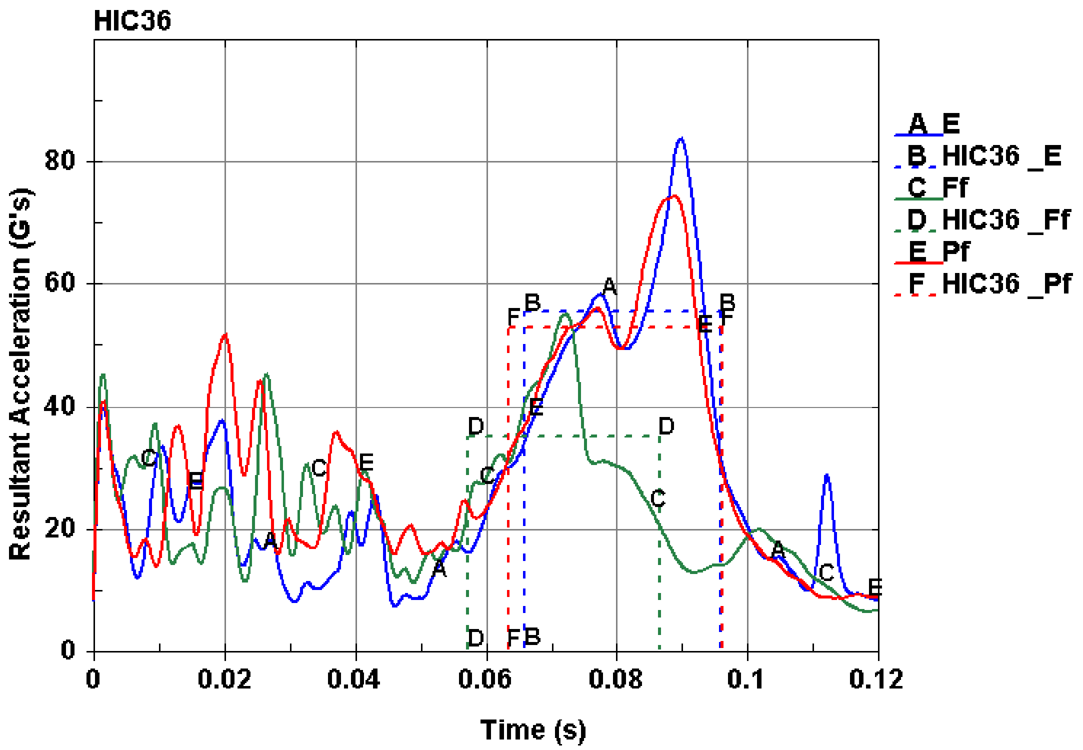


Figure 5. HIC 36 of empty, fully filled and partially filled side member

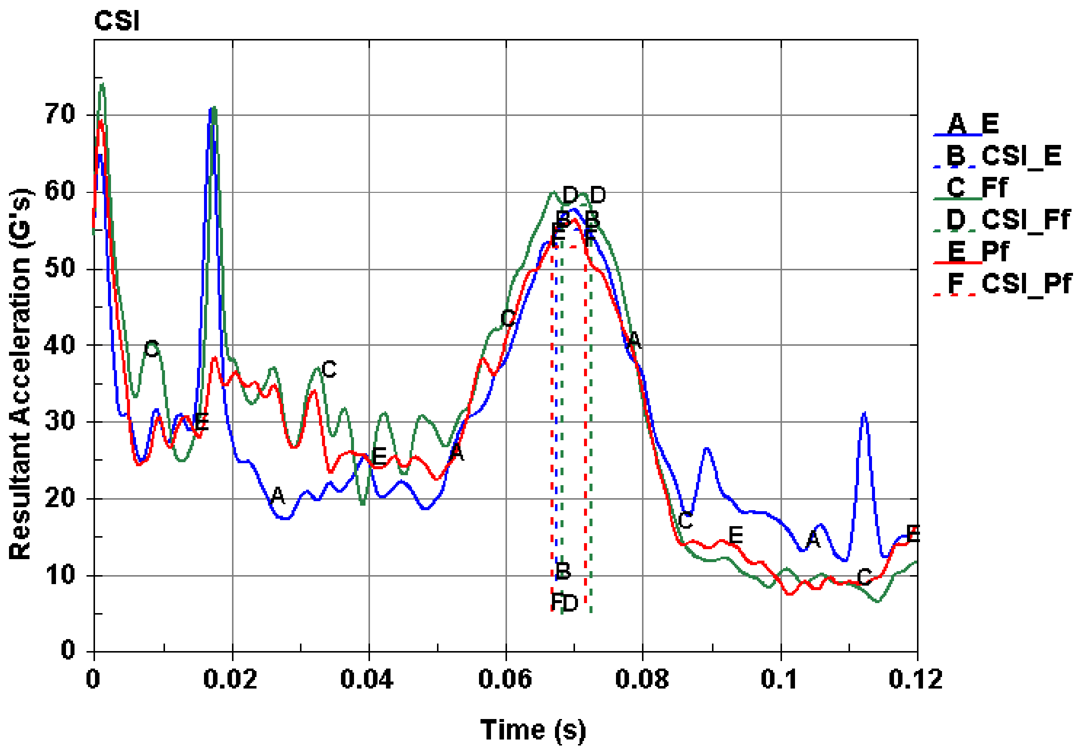


Figure 6. CSI of fully empty, fully filled and partially filled side members

Figure 7 compares the performance of optimal design for a partially filled side member, empty and fully filled side member of the same column thickness. The masses of the empty and fully filled side member in this case are 4.59kg and 5.57kg, respectively. The optimal design of the partially filled side member, with values of

513.6 (HIC15), 677.3 (HIC36) and 807.2 (CSI) and a weight of 5.45kg is found to yield a lower potential of injury, and higher SEA compared to the empty side member. Even though the fully filled side member shows remarkable performance in terms of HIC, it increases the chances of injury to the chest (CSI). Generally, it can be seen that by adding foam filler to the structure, SEA is improved, as found by Guo et. al, 2010.

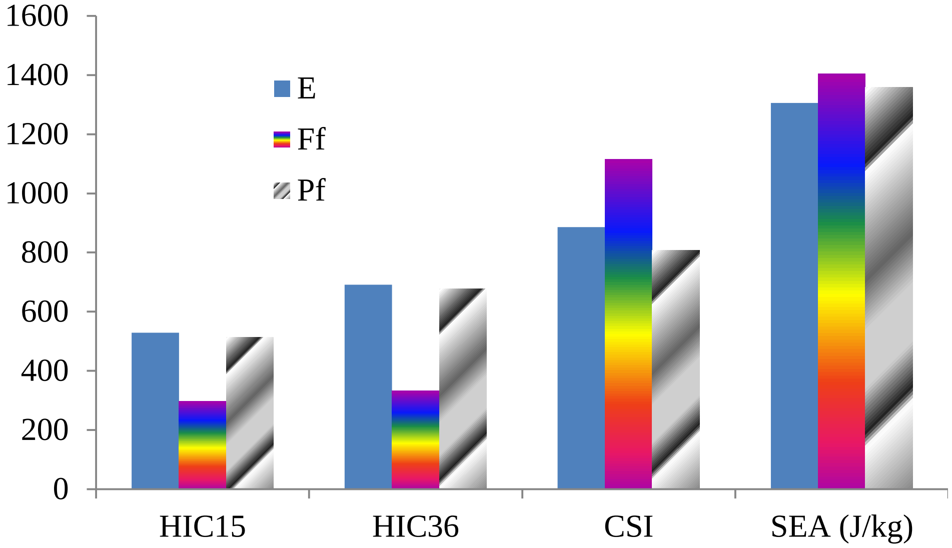


Figure 7. Comparison between the optimal partially filled (Verjedo) side member to the empty (E) and fully filled (Ff) side member of the same column thickness.

CONCLUSIONS

The National Highway Traffic Safety Administration (NHTSA) currently mandates regulatory limits of 1000 for HIC reading and 60g for chest acceleration on the Hybrid III 50th percentile male dummy. These values represent human tolerance to decelerations, above which irrecoverable injury can occur. It is interesting to note that, relatively, Pf is the best design with the lowest index in both HIC and CSI. The small addition of mass in a partially filled column is offset by the overall improvement in occupant protection.

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