Design Assessment for Reusability of an Automotive Safety Beam

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Abstract: Vehicle crashworthiness is one of the key considerations in today’s vehicle development program. The competitive environment requires carmakers to balance between achieving cost and time reduction while improving quality of their products. Quality here encompasses the safety performance in both preventing accidents from happening (active safety system) to protecting passengers from injuries (passive safety system). As reuse aims to sustain the function of old product or components for the second life, it will be necessary to preserve the materials. The other consideration is in terms of reusability of the beam as part of cost consideration especially in low impact scenario whereby deformation of the beam/structure may be minimal. In such cases, the damage or deformation has to be accessed to ascertain whether the beam can be reused. This paper presents a study on the behavior of a door beam upon impact using Finite Element Analysis. The analyses include energy absorption characteristics, deformation and stress of the beam structure and also the effect of impactor on the crash characteristics of the door beam in terms of reusability. It was found that reusability is highly dependent on a number of factors such as the impactor kinetic energy (mass and speed) and materials characteristics. For metallic structure, reusability will be influenced by whether the material undergoes major permanent plastic deformation or behave within the elastic zone upon impact. Once the structure undergoes permanent plastic deformation reusability will not be possible. The results show that for impactor below 20kg, the beam of the car door will deform within the elastic region with the possibility of reusability. However, for load case 30kg and above, the beam undergoes permanent deformation which renders it useless after impact. Further investigation will be necessary to understand how different materials and geometry of the beam can improve the energy absorption characteristics and reduce damage of the car door assembly to enable reusability at the end of its life.

Key word: Automotive component reuse, impact, assembly, durability and materials.

INTRODUCTION

A growing concern about the environment has spurred interest in the design of more environmentally benign products and processes. One of the most pressing environmental problems the Western World is facing is waste management and landfill space. Under pressure by the European governments, global manufacturers are including more and more post life considerations into their product design process (Wahab, 2008). The term recycling is often used for all activities that lead a product, parts of a product, or the constituent material of a product into a new cycle of usage (Wahab, 2008; Jiao, 2000). Both in industry and academia, lots of attention is given to material recycling, in which the geometry of the product (and the associated value) is destroyed and only the constituent materials are led into a new cycle of usage. However, the most dramatic reduction in environmental impact can be made by product reuse and remanufacture in which the geometrical form of the product is retained and the product is reused for the same purpose as during its original life-cycle (e.g., refillable drink bottles and reconditioned car engines) or for secondary purposes (e.g., reuse of automotive tires as mooring cushions in a harbor). Compared to material recycling, the technological base for remanufacturing is relatively small. The role of computer-aided engineering (CAE) in the automotive industry is rapidly increasing. Functional performance attributes (noise, vibration and harshness (NVH), durability) (Guang, 2007), are fine-tuned more and more on the basis of numerical predictions, so that the expensive physical prototyping phase can be shortened considerably. Traditionally, optimizing a vehicle body starts with improving the fundamental torsion and bending frequencies (Paramjot Bedi and Metin Dede). These dynamic characteristics should be robust to failure of beams, thousands of which are present in a typical vehicle body.
As mentioned earlier the product development process has changed not just in automotive industry, but also in the other sectors of the business world. The role of functional design is now at the forefront. Every inch of a car and the parts are now looked at by engineers and marketers with scrutinizing eyes with a view for fuel economy, ease of maneuverability and of course last, but not least safety (Xintao, 2007). When parts/components are to be reused, in either remanufacture or maintenance, the reliability of the parts/components becomes very important. Reliability is defined as the probability that an item to perform a required function without failure under given environmental and operational conditions and for a safe period of time.

Very few studies concentrated on the behavior of components of a car door.. Some of these studies focused on a lightweight design (Xintan, 2007) that proposed a new method for the design of a lightweight automotive body using multi-material construction with low cost benefits. This was taken into consideration with the impact of tolerance sheet gauge, mechanical parameters of material and structure. In order to evaluate reusability, the kinetic energy of an impactor needs to be considered. An impactor with low speed but with a heavy loading may produce more damage to the structure compared to a high speed but light object. Therefore reliability and lifetime prediction of potential reuse assessment will depend on how much energy the structure can sustain or absorb. A metallic structure which undergoes permanent deformation during impact may not be suitable for reuse as changes in the mechanical properties may be significant. Non metallic structures may undergo different deformation characteristics but any effect that reduces the strength of the original structure will not be considered for reusability. In this study, only a metallic structure is considered for evaluation.

2. Methodology:

For the purpose of this study, the door assembly of a locally manufactured car was used as a case example. Using simulation the car door assembly was subjected to an impact force by an impactor as shown in Figure 1. The impactor is given an initial velocity of 30km/h with a load case of 10,20,30,40 and 50kg for the 5 test cases and will hit the door perpendicular to the door surface.

These are caused by some factors that influence the original equipment manufacturers preference of using reuse parts such as the economic benefit and the quality of reuse components. The economic benefit from reuse in the form of reduction in production cost is one of the main concerns. If the cost of producing new vehicles that consist of some reuse parts or components is higher than manufacturing vehicles with all new components, therefore there is no advantage of reuse for the original equipment manufacturers. Therefore we have to examine whether the original equipment manufacturers will gain economic benefits from reuse of automotive components. The other concern is the quality of the vehicles as it is as good as new. As shown in Figure 2 shows the detail assembly with parts thickness of the car door at the driver side.

Fig. 1: 3D model of the door assembly and Impactor.

3. Parametric Study on the Beam:

For the first scenario the low impactor was tested at a level of 10 kg, followed by 20, 30, 40 and 50kg. At the levels of 30, 40 and 50 kg fracture occurs, and the material used in primary tests or simulation is the original material of the car door that is SPCC low carbon steel. In addition, the energy absorbed in these simulations are also investigated and compared to find out the maximum impact before fracture. The simulations were carried out using CATIA®, and data was then transferred to Explicit Finite Element Code and PAM CRASH. This software is used to simulate the crash characteristics of the beams from the moving impactor.
4. Simulation Setup:

By using (Goichi Ben, Yoshio Aoki) steps, in the numerical analysis, a dynamic explicit FEM solver Pam Crash software was employed. The analysis model was created based on the size of the specimens. The analysis model is shown in figure 3. The elastic-plastic shell element low carbon steel material for the beam. The impactor and the brackets were modeled as a rigid car door body. The mass form 10 to 50kg and initial velocity of 30km/h was given to the impactor. The total node number was 23554 and the total element number was 22777. Table 1 shows the material properties of the low carbon steel and figure 4 shows its strain-stress curve of low carbon steel material.

A non symmetrical node to edge contact has been defined for the impactor as the master component and the door skin and beams as the slave component. Additionally, the whole door assembly has been defined with a self impacting node to edge contact to ensure that the interactions of the parts are correctly taken into consideration during the impact. To join the door outer skin and door inner skin, seam welding (ideal connection with no failure) has been defined in assumed locations. Joining of the door beams to the plates and from the plates to the door is assumed to be seam welded. Figure 5 (a), shows that the door is fixed at the hinge position and figure 4 (b), shows that the door is allowed to slide to the other side.

<table>
<thead>
<tr>
<th>Tensile strength</th>
<th>Elastic Modulus</th>
<th>Plastic Modulus</th>
<th>Density</th>
</tr>
</thead>
<tbody>
<tr>
<td>50.04-84.12</td>
<td>36.26-57.29</td>
<td>29.01-31.18</td>
<td>486.9-493.2</td>
</tr>
</tbody>
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Fig. 2: Door assembly showing component thicknesses.

Fig. 3: Constraints on the door structure.
RESULTS AND DISCUSSION

The door structure deforms after the initial impact but as the kinetic energy dissipates through the internal structure in the form of energy used to deform the structure, its momentum gradually becomes less. The resistance to deformation becomes higher and eventually an equilibrium condition is reached whereby the movement of the impactor is stopped by the structural strength. As shown in figure 6 the final deformation is slightly less than during the impacting stage as the door recovers elastically.

Deformation on the door structure caused by the 20kg impactor is more severe, however the door managed to recover elastically whereby the final deformation is less drastic compared to the damage during the impacting stage. As the door assembly structure absorbs the kinetic energy, deformation begins to form and due to the strength of the structure, it managed to recover elastically at some portions. As shown in Figure 7, the final deformation is less compared to during impact.

As shown in figure 8, the 30kg impactor as expected has caused more damage to the door structure. As can be seen here, there are some small elastic recovery in some localized region but this does not help the overall structure integrity. As the energy increases due to the increase in the mass of the impactor, the structure suffers more deformation and from 20kg onwards, the door deforms permanently into plasticity. The severity of the damage can be seen clearly with the door impacted at 50kg as shown in figure 19.

The 40kg impactor as shown in Figure 9 started to cause permanent deformation to the door structure. Deformation at the impacting location is also significant.

As expected the 50kg impactor caused permanent deformation to the door structure. Due to the high momentum and kinetic energy, the beam undergoes high stresses and this causes the structure to go into permanent plastic deformation and thus failure. By comparing the Von Misses stress of the beams under the 5 different scenarios, it is found that the impactor with lower momentum has a lower peak stress. Due to elastic recovery, the beam actually undergoes some springback upon removal or reduction of the impact.

As for the beam with a higher impact/momentum, the peak stress is higher than the yield stress and thus will result in a permanent deformation. Looking at the results, it can seen that impactor up to 20kg will still allow possible elastic recovery on the door structure, while impactor of 30kg causes some slight elastic recovery (localized area) but still insignificant to protect the passenger cabin. Impactor with 40kg onwards causes permanent deformation with high stresses as the material enters the plastic zone. However, at this point it has not reached permanent failure or breaking point.
Fig. 6: Deformation of the door structure using a 10kg impactor.

Fig. 7: Deformation of the door structure using a 20kg impactor.

Fig. 8: Deformation of the door structure using a 30kg impactor.

Fig. 9: Deformation of the door structure using a 40kg impactor.

Fig. 10: Deformation of the door structure using a 50kg impactor.
As shown the average von Misses stress occurs at the centre locations of the beam. The graph, it also shows that impact happens at around 7-8ms for all impactors, and the stresses increase sharply after the impact point. The stress value of the beam in the 10kg and 20kg impactor scenario decreases towards the end as it recovers elastically, while the rest of the beams, indicates high stress values indicating permanent plastic deformation. Based on the displacement results between the 5 scenarios, it can be clearly identified that the beam undergoes minor deformation and after a certain time, recovers some of the displacement (Impactor 10kg and 20kg). For impactor of 30kg, it undergoes some slight recovery in terms of displacement. Comparing with the impactor of 40kg, and above the beam in these scenarios continue to be displaced as the beam fails upon surpassing its yield point and unable to resist the impactor momentum. Thus continuous intrusion of the impactor through the door structure can be clearly seen through the displacement of the beam structure.

Fig. 11: Maximum principle stress for the beam structures.

Comparing the Von Misses stress of the beams under the 5 different scenarios, it can be seen that the impactor with a lower momentum has a lower peak stress. Due to elastic recovery, the beam actually undergoes some springback upon removal or reduction of the impact. As for the beam with a higher impact/momentum, the peak stress is higher than the yield stress and thus results in a permanent deformation. It can be seen that an impact of up to 20kg will still have possible elastic recovery on the door structure, while an impact of 30kg causes slight elastic recovery (localized area) but still insignificant to protect the passenger cabin. An impactor of 40kg onwards causes permanent deformation with high stresses as the material goes into the plastic zone. However, at this point it has not reached permanent failure or breaking point. Maximum von Misses stress occurred on the beam, with the impactor of 10kg causing the least damage to the structure. The Von Misses stress value increases with the increase in impactor mass.

As shown in figure 11, the average von Misses stress occurs at the centre location of the beam. The figure indicates that impact happens at around 7-8ms for all impactors, and the stresses increase sharply after the impact point. The stress value of the beams that experienced 10kg and 20kg impact decreases towards the end as they recover elastically, while the rest of the beams, indicates high stress values indicating permanent plastic deformation. Based on the displacement results between the 5 scenarios, it can be clearly identified that the beams that undergoes minor deformation (impactor of 10kg and 20kg) recovers some of the displacement after a certain period of time. For impactor of 30kg, it undergoes some slight recovery in terms of displacement. Comparing with the results of a 40kg impactor and above, it is observed that the beams continue to be displaced as the beam fails upon surpassing its yield point and unable to resist the impactor momentum.
Fig. 12: Maximum principle stress on the beam structure.

As shown in figure 13, the displacement of the beam occurs at the center location. For the 10kg impactor, the beam does not displace much upon impact and continues to be consistent in terms of the displace value throughout. Impactor of 20kg displaces the beam but after 30ms, the beam starts to recover elastically and eventually the displacement starts to decrease. For the rest of the cases (30kg onwards), the beam continues to be deformed and eventually will lead to permanent failure of the beams. From the energy absorption curve, it can be seen that the beam subjected to the 50kg impactor sustain significantly higher impact energy. However, as all the scenarios uses the same beam both in geometry and material, this study does not compare the efficiency of a particular design in terms of energy absorption characteristic.

Fig. 13: Average Von Misses stress at the centre location of the beam.

Figure 14 shown the comparison of the 5 different cases in terms of energy absorption. The case with highest mass will definitely exhibit higher energy absorption due to the higher kinetic energy sustained.
Fig. 14: Energy absorption of the beam under 5 scenarios.

Conclusions:
This paper explored the assessment for reusability of a car door assembly. First, essential concepts such as intrinsic reusability and effective reusability were defined. Second, the characteristic of reusability was given based on a 5 different scenarios of impact on the door assembly. Finally, the effect of the system configuration on reusability was explained and illustrated. This study would help to enhance the design of an automotive assembly for purposes of recovery at the end-of-life. The analysis will assist in the following: (1) predicting the future performance of the system, (2) designing the system for reusability, and (3) selecting an appropriate configuration from many alternative configurations. Further work will include a study on the strength of the beam by investigating aspects such as geometry, thickness and material variation.

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