Design & Development of Acoustic Baffle by Injection Molding

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ABSTRACT

The current trend NVH plays an important role while designing the BIW of automobile vehicle. Acoustic baffle is one of the important parts of a vehicle which helps in reducing the NVH of vehicle. This report gives the design of baffle for section 8 of lower end of A pillar. Previously baffle was made by pressing the expandable foam material between the two metal plates. These metal plates are replaced by a plastic carries which is made up of polyamide. These plastic carries are manufactured by using the injection molding & after that expandable foam, made of ethylene/vinyl-acetate copolymers (EVA) is overmold on the plastic carrier. Selection of expandable foam material various testing need to be carried out like, temperature storage stability (before & after expansion), adhesion, mechanical behavior, expansion behavior, chemical & corrosion stability. Also snapping feature design provides the advantage of using the same baffle for both right hand side & left hand side of pillar. By using this baffle noise level can be reduced up to 15db. When BIW goes into the electro coat baking oven, the sealing material is being heated to a temperature in the range of the activation temperature. The heat expandable material is sealing the peripheral gap between the carrier and the inner side of the cavity walls. After the expansion of foam NVH test will be carried out at vehicle level to compare the results. The use of expandable foam baffles with plastic material as a carrier replaces the use of metal carrier & thereby reducing the complexity, cost, reduced weight & reduced assembly operations. As the metal part is avoided there is no possibility of rusting of pillars or baffle. Also the main advantage is, the injection molding process gives the consistency in the part & therefore the foam reaches corner sealing with guided expansion.

Keywords— Design of baffle, Injection molding, Material selection, testing, advantages.

1. INTRODUCTION

A. Background

Modern vehicle concepts and structural designs of vehicles have a plurality of cavities which have to be sealed in order to prevent the ingress of moisture and contaminants, since the latter can result in corrosion from the inside on the corresponding body parts. This applies to modern self-supporting body constructions in which a heavy frame construction is replaced by so-called “space frames”. With the latter, use is made of a lightweight, structurally solid chassis made of prefabricated hollow sections. Such constructions have, depending upon the specific system, a number of cavities which have to be sealed against the penetration of moisture and contaminants. These cavities include the upwardly extending A, B and C Pillars supporting the roof structure, the roof rail, portions of the fenders, or the sill. In addition, these cavities transmit airborne sound in the form of unpleasant vehicle running noises and Wind noises, therefore such sealing measures also serve to reduce the noises and therefore to enhance the comfort of traveling in the vehicle.
During the assembly of the car, these frame parts and body parts containing cavities are prefabricated from half-shell components which were joined at a later time by welding and/or adhesive bonding so as to form the closed hollow section. With such a type of construction the cavity in the early body in White ("body shop") state of a vehicle body is accordingly easily accessible, so that sealing and acoustically damping baffle parts (sometimes referred to as "pillar fillers" or "cavity filler inserts") can be fixed in this early phase of body construction by mechanical hanging, by insertion into appropriate holding devices, bores or by Welding to the cavity walls [1].

Most modern baffles are designed to include a sealing material disposed on a support member or carrier. The carrier is generally manufactured from a rigid material, such as hard plastic, such that its shape approximates the shape of the cavity to be sealed. The carrier/sealing material combination is configured such that the carrier is inserted into a cavity, and the sealing material creates an airtight seal between the carrier and the walls of the cavity. Typically, the sealing material is activated (thermally or chemically) after insertion into the cavity so that the sealing material forms a seal with the walls of the cavity [1].

Certain design factors can affect the performance of a baffle. For example, a baffle can include a rigid carrier that supports a layer of expanding foam. The weight and thickness of the rigid carrier can affect how the baffle reacts to various noise and vibration frequencies. Unfortunately, certain baffle designs that include a rigid carrier cannot be modified without expensive changes in tooling and manufacturing. Therefore, it can be time consuming and expensive to tailor a baffle to a particular application, or to change the design to meet certain customer requirements.

II. PROBLEM STATEMENT AN OBJECTIVE
A. Problem Statement
To design and manufacture the acoustic plastic baffle for section 8 of a pillar by using injection molding to reduce the wastage of foam material & ultimately reduce the cost. Instead of using metal nut bolts checking the feasibility of plastic fastener.

B. Objectives
- Reduce the vibration and avoid the entry of contaminants
- Provide the solution of plastic baffles for currently using Metal baffles.
- Use of injection molding to avoid the wastage of foam material.
- Avoiding the use nuts and bolts for fastening to structure.
- Reducing Cost

III. METHODOLOGY
A. Design Calculation
For fitting the metal baffle to the pillar customer is using M8 bolt. Hence from this we have calculated the load which is acting on the bolt.

\[ d = 8 \text{ mm} \]
\[ dc = 0.8 \text{dm} \]

\[ Syt \text{ (Plain Carbon Steel 30C8)} = 450 \text{ N/mm}^2 \]
\[ \text{Factor of safety} = 5 \]
\[ \sigma_t = \frac{Sy}{FOS} \]
\[ \sigma_t = \frac{450}{5} = 90 \text{ N/mm}^2 \]
\[ \tau = \frac{\pi}{4}(d)^2 \]
\[ 90 = \frac{\pi}{4}(0.8X3)^2 \]
\[ P = 2895.29 \text{ N} \]

\[ \tau = \frac{\pi}{4}(d)^2 \]
\[ 45 = \frac{\pi}{4}(0.8X3)^2 \]
\[ P = 1447.64 \text{ N} \]

As tensile load acting bolt is more than the shear load. Hence tensile load need to be used for further calculation.

Section modulus calculations

\[ b_0 = 122.2 \text{ mm} \]
\[ h_0 = 118.2 \text{ mm} \]
\[ d_0 = 70.9 \text{ mm} \]
\[ d_1 = 66.9 \text{ mm} \]
(These are the dimensions of the A pillar Section 8.)

Moment of inertia in X-direction
\[ l_{xx} = \frac{b_0Xd_0^3 - b_1Xd_1^3}{12} \]
\[ l_{xx} = \frac{122.2X70.9^3 - 118.2X66.9^3}{12} \]
\[ l_{xx} = 680078.09 \text{ mm}^4 \]

Section modulus in X-direction
\[ Z_{xx} = \frac{10}{Y_p} \]
\[ Z_{xx} = \frac{10}{680078.09} \]
\[ Z_{xx} = 15.45 \text{ mm} \]

Moment of inertia in Y-direction
\[ l_{yy} = \frac{d_0Xb_0^3 - d_1Xb_1^3}{12} \]
\[ l_{yy} = \frac{70.9X122.2^3 - 66.9X118.2^3}{12} \]
For selection of snapping feature & material we need to calculate the Tensile stress & bending moment developed in the structure.

**Bending moment of beam in X-direction**

As per DSR standard given by customer, door trims are tested against the load of 1500N in X-direction to check the load carrying capacity of door trim.

**Stress induced in X-direction**

As bolts are acting load in Y-direction, hence tensile load \( P = 2895.29 \) N is used for calculating the bending moment & stress induced in Y-direction.

\[
W = 1500N
\]

\[
70.9 \text{mm}
\]

\[
M_x = \frac{WL}{4} = \frac{1500 \times 70.9 \times 0.9}{4} = 26587.5 \text{N} \cdot \text{mm}
\]

Stress induced in X-direction

\[
\sigma_x = \frac{M_x}{W} = \frac{26587.5}{2895.29} = 9.23 \text{N/mm}^2
\]

As the baffle is going to fit in cavity of pillars and it is going to be assembled before baking operation following factors to be considered while selecting material,

a) Yield stress
b) Flexural stress
c) Heat distortion temperature
d) Melting Temperature

\[
\sum M_{R2} = 0
\]

\[
R_1 = \frac{2895.29N \times 16 + 78.9 \times 2859.29}{118.2} = 4204.23 \text{N}
\]

**Bending Moment @ D = 4204.23 X (23.3+16) – 2859.29X16 = 165226.239 – 45748.64 = 119477.599 N-mm**

**Bending moment @ point D has maximum value, hence using this force for calculating stress induced in Y-direction.**

\[
\sigma_y = \frac{M_y D}{I_y}
\]

\[
\sigma_y = \frac{25776.22}{119477.599} = 4.31 \text{N/mm}^2
\]

**Total stress induced in structure,**

\[
\sigma = \sigma_x + \sigma_y
\]

\[
\sigma = 9.23 + 4.31 = 13.54 \text{N/mm}^2
\]

**B. Material Selection**

1. **Plastic carrier**

The rigid support plate is made of polyamide or sheet metal selected from steel, galvanized steel, aluminum or aluminum alloys. The carrier is preferably made from a thermostatic material with a melting point above the activation temperature range. Preferred thermostatic materials are polyamides, polyimides, polyoxypropylene or polyethylene terephthalate, most preferably the carrier is made of polyamide. The polyamide for making the carrier and/or the rigid support plate may contain fibers and/ or inorganic fillers. Also polyamides have good adhesion characteristics which can hold the foam material in place. Polyamides are the group of thermoplastic polymers containing amide groups in the main chain. They are popularly known as Nylons. Polyamides are manufactured either by polymerizing hexamethylene diamine with adipic acid. [1]

- **Characteristics of Nylon**
  a) Hard & tough thermoplastic
  b) Good abrasion resistance
  c) Low coefficient of friction
  d) High tensile strength
  e) Good dimensional stability
  f) Resistance to lubricants, engine oils, grease etc.
  g) High temperature resistance and High water absorption

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a) Yield stress
b) Flexural stress
c) Heat distortion temperature
d) Melting Temperature

2. **Expandable Foam Seal:**

The heat expandable material can be made from ethylene/vinyl-acetate copolymers (EVA), copolymers of ethylene with (meth) acrylate esters, which optionally also contain (meth)acrylic acid incorporated proportionately by polymerization. In addition, the polymer compositions may
also contain cross-linking agents, coupling agents, plasticizers as well as further auxiliary substances and additives. With a view to achieving a sufficient foaming capacity and expandability, these polymer compositions may also contain blowing agents. Suitable, in principle, by way of blowing agents are all known blowing agents such as, for example, the “chemical blowing agents” which release gases as a result of decomposition or “physical blowing agents”, i.e., expanding hollow beads. Preferably, the heat expandable material has an activation temperature below 200°C [1].

Characteristics of EVA [8]
1. Flexible and low temperature toughness (-70°C)
2. Chemically inert.
3. Higher VA content resins possess excellent toughness.
   a. Good resistance to oil and grease.
   b. Low melting point and heat seal temperature.
   c. Low temperature flexibility.

Delfoam K190 was created in order to achieve high requirements specifications in the VW Group. This material started being supplied in 2005 to Seat and has been homologated on each Brand independently (VW/Skoda/Audi/Seat). Thanks to this fact and the high requirements of each brand, ITW has created a high end product, fulfilling the highest requirement on the automobile industry.

ITW’s Foam material K190 main characteristics
1. EVA based material
2. Over 600% expansion rate (by 180°C)
3. Resistant to high baking temperatures (i.e. during paint line failures)
4. High adhesion performance on coated as well as uncoated sheet metals
   a. Low water absorption
   b. No smoke emissions
   1. Compatible to cataphoretic coating, lacquering and paints
   2. Not burnable
   3. Passed emissions behaviour

Material Data sheet of Delfoam K190

![Material data sheet of Delfoam K190](image)

3. Testing of Delfoam K190 Material
1. Temperature storage stability (before expansion)
a. Condition: Material stability and functionality after 24 hours at 90°C
b. Result: After this temperature range, degradation, & fractures or blowing does not appear. Also the change in weight of the foam material was measured, being this minimal. The parts tested for this trial, were submitted to this load under different positions to analyze the behaviour of the part in real assembly situations.

![Specimen before temperature load](image)

![Specimen after 24hours/90°C](image)

2. Adhesion
   a. Condition: Comparison between coated sheet metal & uncoated sheet metal
   b. Results: Adhesion on uncoated serial sheet metals: average 4 N per mm
   Adhesion on coated serial sheet metals: max 4.3 N per mm

![Adhesion testing](image)

3. Mechanical behavior:
   a. Condition: Material stability and functionality at various temperature
   b. Results: At room temperature: High adhesion values achieve, up to 1578 N. After "cold" storage at -40°C / 2
hours: Max. adhesion value of 2933 N. After "warm" storage at 90°C / 2 hours: Max. adhesion value of 100 N

4. Temperature stability (after expansion)
a. Condition: Material stability and functionability at below temperature/time. 180°C / 20min - 200°C / 60min - 220°C / 15min
b. Results: At this temperature ranges, degradation & fractures or blowing does not appear. Also the change in weight of the foam material was measured, found minimal.

5. Climatic change stability
a. Condition: Checking material stability & functionability for below conditions,
   1. Heating from room temperature up to 80°C and 80% humidity in 60min. Afterwards, hold for time of 240min
   2. Cooling from 80°C to -40°C (30% humidity until 0°C) and 240min hold time.
   2. Heating from -40°C up to room temperature (30% humidity over 0°C) in 60min. Total time of trial: 8 cycles x 12h: 96 hours.
b. Results: After 96 hours of climatic change test, no lost of adhesion, breakage, delamination, weight lost or blowing were appearing.

6. Expansion Behavior (Calculated in Laboratory Oven)
4 Modeling of Baffle

The baffle comprises a plastic carrier with a shape corresponding to but smaller than the shape of the cross section of the cavity, and acts as a carrier for a heat expandable material and a heat expandable material mounted only to the outer periphery of the carrier the heat expandable material being adapted to expand at a temperature in the activation temperature range i.e. below 200ºC. The outer rim of the carrier has a flange in L-form which forms, together with the peripheral edge of rigid support plate, a U-shaped groove. This U-shaped groove is adapted to receive the heat expandable material [1].

Advantage of U-shaped groove

a. Directed expansion of the foam material to the gap of the cavity. (Pay for what you use!) No expansion in non-relevant areas.
b. Cost optimized: drastically reduction of the amount of foam material used.
c. Same part can be use on both sides of the car, as the foam material will not fall down.
d. High quality assurance, no risk of foaming on fixing holes for cable clips, plugs.

Figure no 2 shows the environment CAD image of section 8 of Pillar A of BIW. For this section we are designing baffle. Shape of baffle is decided on the basis of cross section of the cavity. Design of BIW undergoes to the no of modification for finalization of vehicle structure. Hence depending on the change in BIW other mating parts also need to modify. Below are the modifications done to get final design.

1. Iteration 1

At initial stage slot size was 8.5mmX8.5mm and panel thickness was 0.8 mm. As per that design was made & weight 17.9gm.

2. Iteration 2

In second modification slot size change to hole size of ø8mm & panel thickness 0.8mm. Location of hole changed to 2mm offset than initial.

3. Final Design

a. Plastic Carrier & Expandable Foam seal

Figure no. 19 Assembly view

Figure no. 19 shows the assembly of Plastic carrier & seal with metal bracket which is customer part. ITW patent snapping features avoid the use of nut & bolt for fixation.
This design provides the locking as an integral part of Baffle. Hence it will avoid one of the assemblies at customer end.

b. Snapping feature

![Snapping Feature](image)

Fig. No 20. Snapping Feature

Second important thing about the design is both side fixation and locking feature permit the use of same baffle for LH & RH side of pillar. This will save the cost of development of new baffle for either LH or RH section.

5. Injection Molding

Injection molding has been a challenging process for many plastic components manufacturers and researchers to produce plastics products meeting the requirements at very economical cost. Since there is global competition in injection molding industry, using trial and error approach to determine process parameters for injection molding is no longer hold good enough. Since plastic is widely used polymer due to its high production rate, low cost and capability to produce intricate parts with high precision [9]. We are using over-molding process for manufacturing the baffle. In metal baffle expandable foam material is sandwiched between two metal plates. While in plastic baffle we are over molding the expandable foam material on plastic carrier. This will give a continuous flow of material which avoids the stress concentration at certain point.

![Overmolding of Baffle](image)

Fig. 21 Overmolding of Baffle

No assembly needed: the foam material is directly overmolded around the ground body. Both parts inseparably connected before and after the expansion process at the OEM.

4. ANSYS RESULTS

![Maximum von-Mises Stress](image)

Fig. 22 Maximum von-Mises Stress

Analysis result and calculated result is same.

4. COMPARISON BETWEEN METAL & PLASTIC BAFFLE

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Metal Baffle</th>
<th>Plastic Baffle</th>
</tr>
</thead>
<tbody>
<tr>
<td>Design</td>
<td>Foam material sandwiched between two metal plates</td>
<td>Unshaped groove design for effective use of foam material</td>
</tr>
<tr>
<td>Injection molding</td>
<td>Possibility of insufficient material at some places</td>
<td>Automated process with Robo assisted design and providing more consistency</td>
</tr>
<tr>
<td>No of parts</td>
<td>Three parts i.e. two metal plates &amp; foam layer</td>
<td>One piece construction</td>
</tr>
<tr>
<td>Assembly</td>
<td>Welding of baffle to the cavity of pillar.</td>
<td>Reduces welding, assembly at Tier1 eliminating logistic issue. Ease of Assembly at OEM with click – on solution</td>
</tr>
<tr>
<td>Material Cost</td>
<td>Steel Plates-350 Rs/kg (inc.molding)</td>
<td>Zord 10/1L 272 Rs Kg</td>
</tr>
<tr>
<td></td>
<td>Foam-900 Rs/kg</td>
<td>Dafault 350-660 Rs Kg</td>
</tr>
<tr>
<td>Cost of Baffle</td>
<td>70 Rs/part</td>
<td>70 Rs/part</td>
</tr>
</tbody>
</table>

REFERENCES

[1] Jean-Pierre Monnet, Boulleret (FR); Fabrice Prunaret, Saint Bouver (FR); Sebastien Peget, Saint Bouize (FR); Gregory Magnet, St.Loup (FR), Acoustic baffle, US 20110057392A1, Mar. 10, 2011.


