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# Redesign of Catalytic Converter Substrate

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**Abstract:** Improvement in design of catalytic converter requires better understanding of complex processes involving fluid flow, chemical reactions and fundamentals of heat and mass transfer. Stringent emission regulations around the world necessitate the use of high-efficiency catalytic converters in vehicle emission systems. The rare earth metals used as catalyst to reduce $No_{x,}$ $CO_x$ and Unburned Hydrocarbons are costly and scarce. The unavailability and high demand of present catalyst materials necessitate the need for finding out the alternatives. In the present work, the modelling of ceramic monolith substrate with square shaped channel type of Catalytic converter and insertion of platinum and palladium aerogels to provide better cost efficiency and replaceable aerogel instead of replacing the complete unit, using Solidworks have been designed. Simulation for the body casing is done using SOLIDWORKS and meshing of substrate is verified using ANSYS R15.0 for nodes and elements. The cost optimisation due to usage of aerogel is explained.

**Key words:** Catalytic Converter · Redesign · Cost reduction · Aerogel

## INTRODUCTION

In theory, Hydrocarbons with gasoline are combusted using atmospheric Oxygen to give Non-Toxic end products ($CO_2$ & $H_2O$). But in reality, due to incomplete combustion and presence of minimal impurities in the fuel can result in the formation of toxic $CO_x$, $NO_x$ and Unburned Hydrocarbons. One of the solutions for a safer exhaust gases is in the conversion of harmful emissions into harmless end products is by the use of catalytic converters.Visually, there is negligible change in what goes in and what comes out of the converter. But there are reactions that take place inside this revolutionary equipment used for emission control.

“A catalyst enhances chemical conversions/ reactions to occur more rapidly at lower temperatures to obtain desired products.”

Automotive emission catalytic converters consist of special combinations of precious metals such as Platinum, Palladium made available as aerogels, are inserted into high surface carriers which in turn are coated with chemicals on walls of ceramic or metallic monolithic structures.Other than the thermal analysis and other mechanical factors to be considered, one basic process to be understood in the working of the converter is a few chemical reactions. The equipment proposed, is a Three Way catalytic converter (TWC) used to treat full/ partially unburned hydrocarbon, carbon monoxide and nitrogen oxides by running on three simultaneous functions:

Reduction of nitrogen oxides into basic nitrogen & oxygen:

$$NO_x \rightarrow N_x + O_x$$

Oxidation of carbon monoxide to carbon dioxide:

$$2CO + O_2 \rightarrow 2CO_2$$

Oxidation of hydrocarbons into carbon dioxide & water:

$$C_xH_{4x} + 2xO_2 \rightarrow xCO_2 + 2xH_2O$$

There are two types of "systems" running in a catalytic converter, "lean" and "rich” [1]. When the system is running "lean," there is more oxygen than

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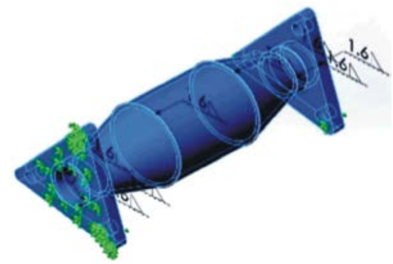
required by the system and the reactions therefore favour the oxidation of carbon monoxide and hydrocarbons (at the expense of the reduction of oxides of nitrogen). On the contrary, when the system is running "rich," there is more fuel than needed and the reactions favour the reduction of nitrogen oxides into basic nitrogen and oxygen (at the expense of the two oxidation reactions). With constant imbalance of the reactions, the system never achieves 100% efficiency. Converters can store "extra" oxygen in the exhaust stream for later use. The storage usually occurs when the system is running lean; the gas is released when there is not enough oxygen in the exhaust stream. Released oxygen compensates for lack of oxygen derived from $NO_x$ reduction process, or when there is hard acceleration and the air-to-fuel ratio system becomes rich faster than the catalytic converter can adapt itself. In addition, the release of the stored oxygen stimulates the oxidation processes of CO and $C_xH4_x$.

## MATERIALS AND METHODS

Working media here is the exhaust released from engine and that is assumed to be a steady and compressible fluid. Material used for the Honeycomb Monolith is synthetic cordierite. The preference is such, due to the following reasons; low thermal coefficient of expansion, capacity to manufacture a concentrated 62 cells per square centimetre [2], an approximate dimension of 1mm width and 0.15mm thick cell can be fabricated. Manufacturing of substrate is done by extrusion of paste cordierite, subjective drying and calcination [3]. The factors that compel this selection are; better cost efficiency and also that it is a widely preferred manufacturing method. The involvement of aerogels as the main catalysts in all reactions is done as, only 11.92% of metal and rest is air, 0.582 grams is the mean gross weight, a maximum of 80% saving in volume of metal is possible and hence cost efficiency improves by 65% and also has the least thermal expansion. Also, thermal and pressure simulation is done using simulation module and mesh validation of the substrate in terms of nodes and elements is verified. The weld beading used while modelling, is specified as regular GTAW electrode of diameter 1.6mm [4] and is clearly marked during the simulation to prevent mislead interpretation of design.

Platinum based aerogel is suggested [5] for use in the slots provided as shown in the model.

Material Properties

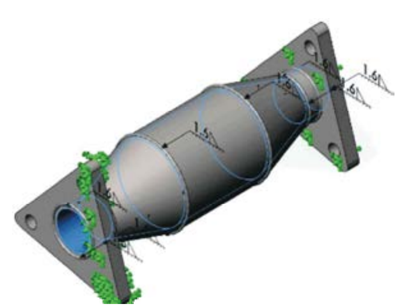


| | |
|---|---|
| Name: | Cast Stainless Steel |
| Model type: | Linear Elastic Isotropic |
| Default failure criterion: | |
| Elastic modulus: | 1.9e+011 $N/m^2$ |
| Poisson's ratio: | 0.26 |
| Mass density: | 7700 $kg/m^3$ |
| Shear modulus: | 7.9e+010 $N/m^2$ |
| Thermal expansion coefficient: | 1.5e-005 /Kelvin |

## Results and Tables

The sustenance of the casing under various physical conditions is discussed here. The study properties are:

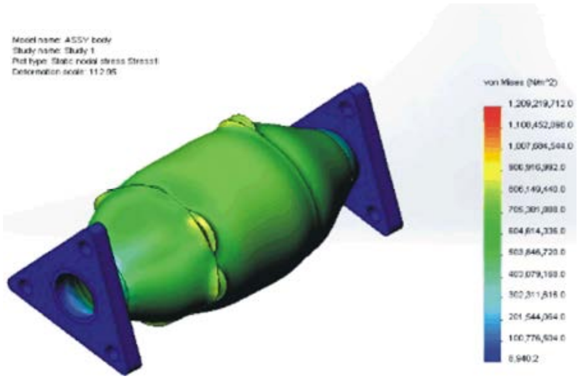
| | |
|---|---|
| Study name | Final Pressure |
| Analysis type | Static |
| Mesh type | Solid Mesh |
| Thermal Effect: | On |
| Thermal option | Include temperature loads |
| Zero strain temperature | 298 Kelvin |
| Include fluid pressure effects from SolidWorks Flow Simulation | On |
| Solver type | FFEPlus |
| In plane Effect: | On |
| Soft Spring: | Off |
| Inertial Relief: | Off |
| Incompatible bonding options | Automatic |
| Large displacement | On |
| Compute free body forces | On |
| Friction | Off |
| Use Adaptive Method: | On |
| Unit system: | SI (MKS) |
| Length/Displacement | mm |
| Temperature | Kelvin |
| Angular velocity | Rad/sec |
| Pressure/Stress | N/m2 |



Load Details

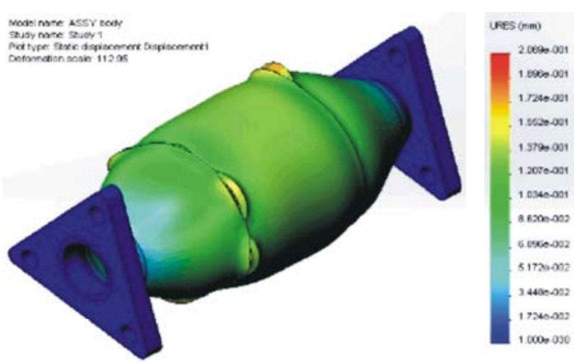
| | |
|---|---|
| Entities: | 5 face(s) |
| Type: | Normal to selected face |
| Value: | 89 |
| Units: | $N/mm^2$ (MPa) |

| Name | Type | Min | Max |
|---|---|---|---|
| Stress1 | VON Mises Stress | 8940.16 N/m$^2$<br>Node: 8829 | 1.20922e+009 N/m$^2$<br>Node: 3765 |



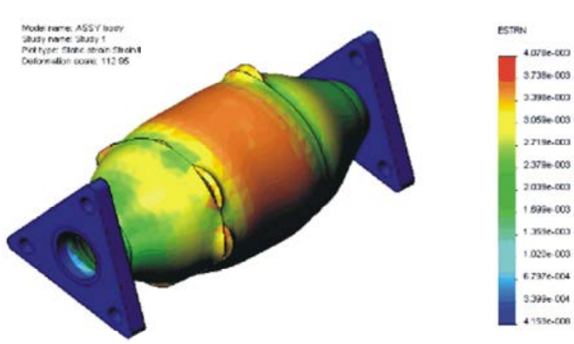
ASSY body-Study 1-Stress-Stress1

| Name | Type | Min | Max |
|---|---|---|---|
| Displacement1 | URES: Resultant Displacement | 0 mm<br>Node: 4846 | 0.206868 mm<br>Node: 14299 |



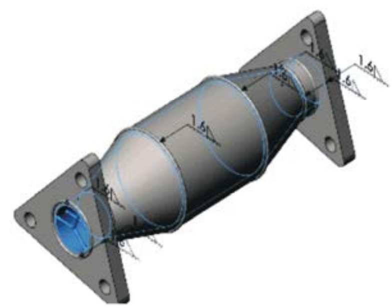
ASSY body-Study 1-Displacement-Displacement1

| Name | Type | Min | Max |
|---|---|---|---|
| Strain1 | ESTRN: Equivalent Strain | 4.15942e-008<br>Element: 4927 | 0.0040781<br>Element: 2136 |

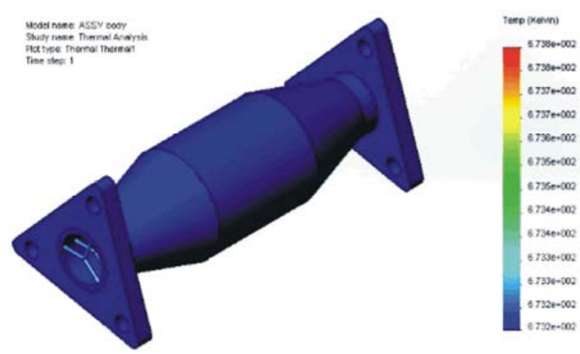


ASSY body-Study 1-Strain-Strain1

| Study name | Thermal Analysis |
|---|---|
| Analysis type | Thermal(Steady state) |
| Mesh type | Solid Mesh |
| Solver type | FFEPlus |
| Solution type | Steady state |
| Contact resistance defined? | Yes |
| Unit system | SI (MKS) |
| Length/Displacement | mm |
| Temperature | Kelvin |
| Angular velocity | Rad/sec |
| Pressure/Stress | N/m$^2$ |

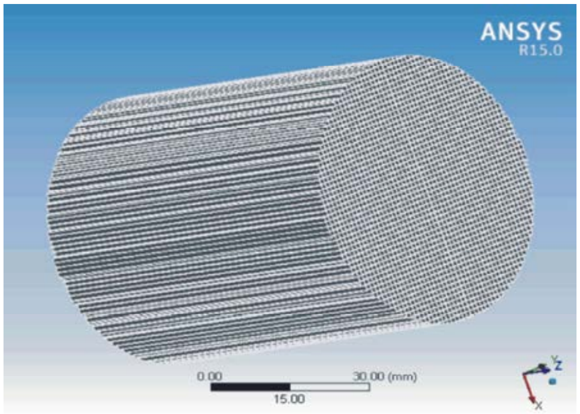


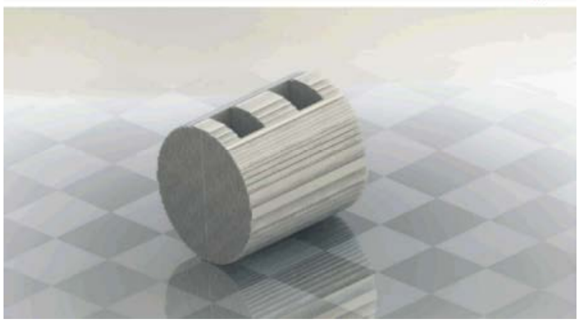
| | |
|---|---|
| Type: | Temperature |
| Min: | 673.15 Kelvin |
| Node: | 1 |
| Max: | 673.15 Kelvin |
| Node: | 1 |



**Explanation of Cost Reduction:** Along with environmental considerations, the usage of aerogels also signifies the overall economic impact in using precious metals as catalysts. For instance, platinum costs more than $1500 [6] per ounce and the usual requirement of platinum per catalytic converter is as much as half an ounce. If aerogels can save up to five times the material [7], then even the cost that is required for procurement can be significantly dropped, thereby saving up to 80% in material and improving the cost effectiveness by 65%.In all, ensuring the same performance [8] as a solid metal, the usage of platinum aerogel widely, may now be in reach[9,10].

Mesh Validation



Statistics
Nodes 239355
Elements 169494

## CONCLUSION

The following conclusion can be made from the above results.At extreme pressure condition, the deformation scale was 112.95e-001, which confirms a safe design structure for the casing. At extreme thermal endurance, the system is very stable as it is visible in the safest region (blue shaded).

**Possible Future Works:**

Fabrication of this model and testing for practicality.
Test for Euro standards of emission control.
CFD simulation using Fluent in ANSYS Workbench.

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