

Prediction of Catalytic Converter Durability Using Hot Push-out Test Methods

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ABSTRACT

Catalytic converter mechanical robustness depends on maintaining a certain range of mat pressure to firmly hold the honeycomb ceramic substrate from moving inside a catalytic converter during its service life while avoiding fracturing it in the manufacturing process. Durability, robustness and performance of the converter assembly need to be predicted for designing the mounting system parameters.

This paper investigates the major factors that affect the mat holding force. An innovative substrate hot push-out test method is presented to measure the mat holding force, providing the key performance data earlier in the design cycle. DOE data along with statistical analyses are presented showing the correlation between the mat holding force and various key factors.

Hot push-out test can be used to replace the current key-life testing method as a cost effective pre-screen test method that enables robust design earlier in the design cycle. It can also be used as a prediction of catalytic converter's durability performance.

INTRODUCTION

Catalytic converters have become more and more common in gasoline engine vehicle exhaust systems since it was introduced into US automobiles for the 1975 model year to comply with tightening EPA regulation on auto emissions. Most recently, diesel engine exhaust systems have joined in also to meet the tightening EPA emission regulations, with their own unique development problems. A diesel engine exhaust system may need a diesel particulate filter and a diesel oxidation catalyst, in addition to the catalytic converter.

A typical catalytic converter system consists of three main components: a coated substrate, a supporting mat, and a metal housing. A diesel particulate filter or a diesel oxidation catalyst usually has the very same main components of a catalytic converter and are very similar in structure.

In a converter, the substrate wrapped with mat is inserted into the metal housing. A certain compressive pressure is applied on the mat which is sandwiched between the substrate and the housing. The role of mat material is to hold the substrate, allow for thermal expansion, seal the gap between the substrate and the housing, provide thermal insulation, absorb impact force and even reduce gas flow noise; all throughout the useful life cycle of the converter.[4] [5] One important challenge in catalytic converters is to decide a proper mat pressure. Nowadays, the majority of substrates in automotive application are made of ceramic honeycomb materials which are brittle in some directions. If the mat pressure is too low, the mat will not provide sufficient holding force to prevent the substrate from moving inside the metal housing, which will finally result in damaging the substrate. On the other hand, if the mat pressure is too high, the holding force will induce cracking or fracture to the fragile ceramic substrate. Both cases result in dysfunction of the catalytic converter for emission control, namely, the environmental protection.

A converter system designer needs to define a proper range of mat pressure so that the housing can hold the substrate robustly but does not compress the substrate too hard. However, in current manufacturing processes, both the dimensions of ceramic substrates and the basis weights of fibrous mats are of comparatively large tolerances. For design engineers and manufacturing engineers, it is a challenge to determine the proper system/components and process parameters. Cracked substrates may be detected in the manufacturing process, although substrates coated with precious metals are very expensive. However, loosened substrates can only be found during vehicle operation. It causes customer complains and warranty returns.

In most cases, the moving of a substrate is caused by the loss of mat holding forces due to its deterioration, while the ceramic substrate and the stainless steel housing are comparatively stable. The properties of mat materials are affected by pressure, heat, air blow, aging, vibration force, etc.

A catalytic converter design has to be verified and validated to meet the emission requirement for the whole useful life of the vehicle, namely 15 years or 150,000 miles whatever comes first. In the current automotive industry, one of the common durability tests is the Key-life Testing method: the Hot Vibration Test. The tested converter is mounted on a shaker table at a 45 degree angle to the vibration system platform (armature). During the testing, the sinusoid vibration is controlled at 185 Hz and 28 g constantly while hot exhaust air flows through the converter at a temperature and flow rate depending on the vehicle engine operation conditions. In the current design verification test, samples are required to pass 100 hours and/or 250 hours without substrate axial movement more than 2 mm inside the housing, or without substrate cracks or fracture.

This kind of test not only requires long test duration, but also needs complex vibration equipment. Both time and cost limits the research and develop of a new design. Product design engineers for catalytic converters need to find a cost-saving and time-effective prescreen test methodology to verify their advanced designs quickly and easily in the design cycle.

One approach is called Accelerated Robustness Test, or Step Stress Test. In this test, the vibration frequency is random rather than constant in the above mentioned traditional tests. The power spectrum density (PSD) level increases exponentially after each step of testing is passed. This kind of test significantly reduces test duration. [1]

Considering that the moving of a substrate is caused by mat deterioration, a new approach, Hot Push-out Test, is put forward to directly measure the mat holding force. During the testing, the substrate's push-out force is measured while the hot exhaust gas is forced through the converter.

The study consists of two phases. First, study shows that the hot exhaust air bowing though the converter plays a much more important role than vibration in the deterioration of mat properties. Then a large DOE is employed to identify the major factors that affect the mat holding force. A highly-confident correlation of mat holding force vs. key-life (hot vibration) test duration (hour) provides a landmark premise of the new verification method.

EXPERIMENTAL

MAT HOLDING FORCE

The substrate is held by the mat wrapping around it. (See Figure 1) Compressive pressure is built up during the canning process. The converter is subjected to outside forces (F) during the vehicle operation. The friction (f) between the mat and the brick, or the friction

between the mat and the housing, prevents the substrate from moving relative to the housing only if the f is no less than F.

The friction, f, is

$$f = \mu(N) = \mu(p)(A) = \mu(p)(\pi DL) \quad (1)$$

Here,

μ is the coefficient of friction

N is the normal force acted on the substrate or housing

p is the pressure

A is the mat area

D is the diameter of substrate

L is the width of the mat

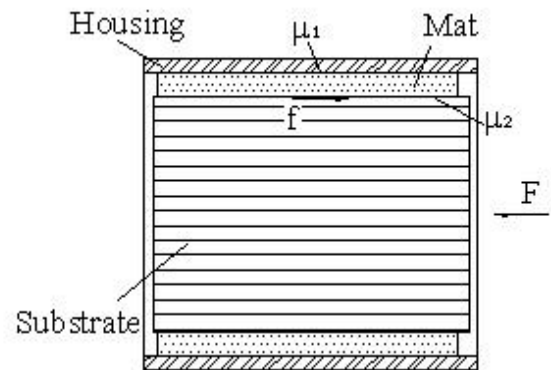


Figure 1 Mat Holding Force (f)

However, in the current production, there are relatively large tolerances of mat material weight and substrate dimensions. The observed substrate movement occurs dominantly in the interface between substrate and mat rather than between mat and housing.

The coefficient of friction, μ , is depending on many variables, such as surface condition, temperature, aging, exhaust gas composition, vibration forces, organic binder, etc.

Also, the build-up compressive pressure, p, is depending on variables, such as mat GBD, temperature, gases, aging, fiber, binder, vibration forces, etc.

The force exerted on the substrate, F, is a combination of gravity, vibration, impact, gas pressure, etc.

HOT PUSH OUT TEST METHOD

The test fixture is built on a universal material test machine having two vertical pillars, a crossbeam above and an actuator below (Figure 2). One end of the tested converter is seated vertically on a frame mounted on the hydraulic actuator from the bottom of the tester. Through the frame, a flex pipe is connected to the converter and the hot exhaust gas blows into the converter and discharges at the top. Under the over-heat, a rod with an enlarged flat end-face is

inserted into the opening of the converter. Before measurement starts, the actuator slowly moves up and stops until the tool contacts the substrate to be tested and a small preset force is detected to guaranty the full contact of the tool to the substrate. An LVDT (Linear Variable Differential Transformer) is attached to one pillar of the tester and its core rod rests on a metal plate attached to the converter housing. A data acquisition system simultaneously records the hydraulic actuator's push force as well as the LVDT displacement (substrate movement). During the testing, temperature and gas flow rate are controlled by thermocouples and flow meter.

In this study, both exhaust gas temperature and flow rate are kept the same as used in current hot vibration test.

The actuator's linear velocity is set at 2.54mm per minute.



FIGURE 2 TEST FIXTURE IN OPERATION

Figure 3 is a typical plot of the hot push-out test results. From it, we can get the static friction force, dynamic friction force, and the slope (mat shear module). Only the static friction forces are used for the purpose of the paper.

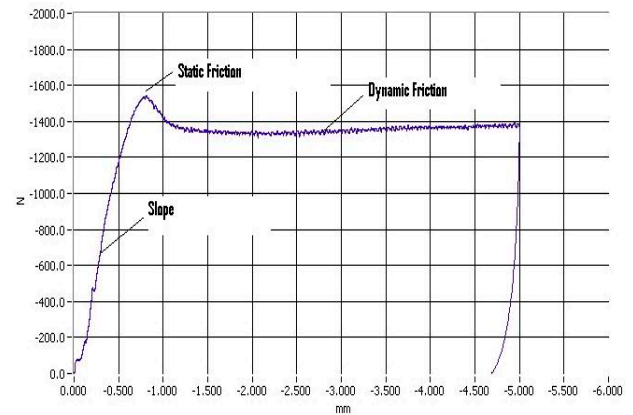


Figure 3 Push-out Force

SPECIMENS

The catalytic converter designed for a high-volume vehicle program is chosen as the sample for this study. It contains 2 round substrates both supported with non-intumescent mats. Special specimens are built at company's prototype shop and production line in three different gap bulk density (GBD) groups covering specific design tolerance specification.

Substrates

The converter contains 2 round ceramic honeycomb substrates. Both are 4.66" in outer diameter. The inlet one is 3.50" in length and the outlet one is 4.69".

Mats

Both the inlet and outlet supporting mats employed in this converter are non-intumescent with film laminate. The basis weight of the inlet mat is 2000 g/m² and the basis weight of the outlet mat is 2100 g/m².

Gaps

Every substrate's outer diameter is measured, so does every mat weight. The substrate wrapped with supporting mat and secured with a masking tape, is inserted into a stainless steel tube, which is then swaged into a smaller preset outer diameter, so that every converter has desired gap, or mat GBD. Three groups (A, B and C) of converters are prepared. Samples of group A. have low GBD, group C high GBD, and group B the average of A and C.

Preconditioning

For comparison, a half of the tested converters were preconditioned with 10 cycles of water quenching.