

# Evaluation and Prevention of Corrosion Risks for Light Weight Automotive Exhaust Components

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## ABSTRACT

The purpose of this paper is to highlight the importance of material and design selection for future light weight exhaust systems. Material validation for new components usually requires various types of tests on different types of test coupons. There are varieties of corrosion test methods which are in practice since years now. Majority of these testing approaches are used to make relative ranking among different materials. In most of these tests a correlation between testing and field behavior is missing. There is also no test available in which both external as well as internal corrosion can be realized simultaneously. Additionally, none of these corrosion tests cover the design aspects of the components. To combat this challenge Faurecia has built and validated a corrosion test setup where complete exhaust silencer can be tested near to real conditions. A comparative study was performed between field parts and test parts to validate the test cycle. The test results are satisfactory and duplicating the real-world performance. With the help of this method an accurate material and design selection can be made.

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## INTRODUCTION

An average exhaust system mass is around 2-4% of the total mass of vehicle. The exhaust system is one of the parts in a vehicle where material thickness has changed dramatically over the past five plus years now. Global trends toward CO<sub>2</sub> reduction and to improve fuel economy have significantly contributed to this trend of weight reduction. On the other hand, corrosion is still one of the biggest concerns due to which automotive exhaust components have a limited life time. A very high rate of corrosion in automotive exhaust components more likely in silencers is one of the biggest problems that automotive industry is facing since long time ago. A large variety of exhaust silencers having different design characteristics are available in an automotive market. They can be divided into various types like clamshell silencers, wrapped silencers, deep drawn silencers, lock seam silencers, welded silencers etc. However, different designs can also utilize different types of materials. In past the predominantly used materials for exhaust silencer applications were low carbon steels and aluminized mild steels. Later on they were replaced by materials of high corrosion resistance, such as stainless steels and aluminized stainless steels [1, 2, 3, 4, 5, 6, 7, 8]. Use of ferritic chromium stainless steels, ferritic chromium-molybdenum stainless steels and austenitic stainless steels are most common today. However, stainless steels do not possess unlimited corrosion resistance due to aggressive operating conditions [9-10].

The number of corroded parts is still relatively high due to a variety of corrosion phenomenon which happened in field. The position of a silencer is in a rear part of an exhaust system. It is considered as a colder part of an exhaust system as compared to the parts near to an

engine. An exhaust silencer is a complex assembly of various components, performing important tasks under harsh conditions. The life time of a silencer is shorter as compared to any other part of an exhaust system. The major causes of premature silencer failure are corrosion, fatigue or a combination of both. Of all automotive exhaust failures, about 80% are caused by different mechanisms of corrosion while the majority of the remainder is caused by fatigue [11]. Some of them are highlighted as following:

- Internal corrosion due to acidic condensate
- External corrosion from de-icing reagents used on icy roads
- Material sensitization especially on hot spots (material temperatures up to 500°C are typical for rear silencers and 600°C for front silencers)
- Static loads due to the mounting of the system and internal stresses
- Thermo-mechanical loads due to heating and cooling cycles (low cycle fatigue)
- Vibrations from the engine (high cycle fatigue)

To simulate these conditions some standard testing methods are used worldwide. For external corrosion, salt spray tests and for internal corrosion, dip and dry tests are performed in different ways. All these types of tests provide information about relative ranking of different grades under different conditions. To predict the life time of a complete system under real conditions is not possible with these tests. There is no standard test available which can simulate the real conditions of an exhaust system. A fundamental understanding on the interaction of thermal shocks and wet corrosion with a component

testing method is presented in the paper. A comparative study was performed between field systems and test systems to establish a relation for the life time calculation.

## EXPERIMENTAL DISCUSSION

There are some standard methods which are usually performed by every steel supplier and automotive exhaust manufacturing companies to screen and rank the different materials. In order to duplicate the wet corrosion in exhaust components, three types of corrosion tests are in practice. Salt spray test to simulate the external corrosion, a well-known dip & dry test for the internal acidic corrosion and electrochemical investigations to rank the grades in different mediums. Every producer performs these tests with some modifications including different test parameters. The purpose of using these accelerated corrosion testing methods is to have an approach of a product's performance in field by simulating in the laboratory sites. Some essential tests are explained as follows:

### Salt Spray Test

The salt spray test is the oldest and frequently used test in an automotive industry to investigate the corrosion behavior of various materials. This practice provides a controlled corrosive environment which has been utilized to produce relative corrosion resistance information of different materials [12]. By additional temperature cycles, salt spray chamber can be used to replicate conditions encountered at cold end in a real driving cycle. The most commonly used test methods are ASTM B117 and VDA 621-415. The reason that these test methods do not accurately reproduce corrosion performance for automotive exhaust parts is that they do not accurately reproduce the conditions in which automotive parts must exist. For one thing, parts tested in a salt-spray cabinet are continuously wet, while those parts on a vehicle experience periods of wetness and dryness. Another difference includes the temperature changes that occur in the real world and the fact that real-world conditions include salts other than NaCl. The result is that salt spray test methods produce different corrosion mechanisms and different corrosion products than the more realistic way.

### Dip and Dry Test

The dip and dry test is widely used in the automotive industry for accelerated cyclic corrosion tests in changing wet, humid and dry environment [13, 14, 15]. This test simulates the internal corrosion in exhaust components. Dip and dry test procedures are different and all manufacturers perform these types of tests according to their own experience and specifications. There are also no standard test methods available like salt spray tests. The concentration of condensates also varies from pH 2.0 to pH 10. Dip and dry tests are often criticized, for unrealistic test conditions leading to poor correlation with in-service or real environment performance and the question how meaningful the test data is, as well as specimen to specimen and chamber to chamber variations.

## Electrochemical Tests

Electrochemical measurements including potentiodynamic polarization curves are also used in normal routine to study the performance of the material under different conditions. These tests are the fastest available methods where one can achieve results in a short period of time. Also, corrosion potential in mediums like salt solution and exhaust condensates are normally measured for different materials. Corrosion potential gives a relative thermodynamic “ranking” of a metal or alloy in a given environment. In general, a more positive corrosion potential means that the metal can be expected to be more resistant to corrosion in that particular electrolyte than one with a more negative corrosion potential. All these tests are used to obtain instantaneous corrosion rates for making a preliminary selection of the best candidate materials. As a rule of thumb, materials with higher PREN number are more resistant to pitting corrosion.

## Vehicle Test

For the confirmation of the implemented measures against corrosion attack within the development phase the final test which would be conducted is a vehicle corrosion test. There are various vehicle tests performed by different car manufacturers to estimate the total vehicle corrosion resistance. Some tests like KWTDC (Daimler) [16], MAN [17], INKA (Audi), DYKO (BMW) and Global 12W-TVACT (Ford) are well known worldwide. These corrosion tests are not designed for exhaust components. The main focus of these tests is to evaluate the corrosion behaviour of car body.

All the explained tests will not be able to fully mimic the complexity of all interactions between designs and material on one hand, and various environmental stress factors on the other, to the right proportions. In some cases the conditions are very aggressive while in other cases the situation is totally different. There are stochastic or drifting variations in the manufacturing processes that a single test is unable to cover (“piece-to-piece variation”). To obtain the comparable results would lead to very high costs. Only one exhaust system could be tested during one vehicle test. To test the behaviour of various systems in one test is not possible.

## CORROSION RIG COMPONENT TEST

A concept of testing a complete system under conditions near to the actual problem was initially proposed and test setup was designed. The idea behind this proposal was to develop a testing method in which the real problems from the field can be simulated. This corrosion rig has been developed to validate the corrosion resistance of components in a short period of time. To investigate both external and internal corrosion with additional heating influence in a one test was the task. A testing chamber with heaters, blowers and pumps was constructed. The following different conditions can be programmed individually:

- Hot gas flow with various flow rates up to maximum 650°C depending on the service temperature for the investigated part
- Injection of an artificial condensate in air stream
- Salt spray conditions with help of different nozzles
- Water or salt water sprinkling including a thermal shock effect