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*Research Article*

# A New Testing Method for Lifetime Prediction of Automotive Exhaust Silencers

**Muhammad Yasir,[1] Gregor Mori,[1] Helmut Wieser,[2] Martin Schattenkirchner,[2] and Manuel Hogl[2]**

[1] *Christian Doppler Laboratory of Localized Corrosion, University of Leoben, 8700 Leoben, Austria*
[2] *Faurecia Emissions Control Technologies, 86154 Augsburg, Germany*

Correspondence should be addressed to Muhammad Yasir, yasiryounas3@gmail.com

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The purpose of this paper is to highlight the problems associated with daily routine corrosion tests performed in an automotive exhaust industry. Estimation of the life time of a complete system under real conditions is always uncertain and often leads to a disagreement. A new testing setup was built in which simulation of external and internal corrosion with additional thermal cycles can be performed simultaneously. Simulation of all real conditions makes this test totally versatile and unique among all the existing testing methods. All test results were investigated quantitatively and a direct comparison was made between some field systems with different mileage and total life. Conformity was accomplished between the results from corrosion tests and parts from the vehicles. Studies carried out on the silencers have shown that the new component testing method could be used for life time estimation of parts having different material and design combinations. On the basis of obtained results it can be stated that the new testing setup can be applied for different materials and design rankings.

## 1. Introduction

Corrosion is one of the biggest problems due to which automotive exhaust components have a limited lifetime. A very high rate of corrosion in automotive exhaust components more likely in mufflers 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 mufflers, wrapped mufflers, deep drawn mufflers, lock seam mufflers, welded mufflers, and so forth. Like the variety of designs, the use of different grade materials is also quite often. In the past, the predominantly used materials for exhaust muffler applications were aluminised mild steels. Later on, they were replaced by the materials of high corrosion resistance, such as stainless steels and aluminised stainless steels [1–8]. The use of ferritic chromium stainless steels, ferritic chromium-molybdenum stainless steels, and austenitic stainless steels are most common nowadays. Even stainless steels do not possess unlimited corrosion resistance due to aggressive operating conditions.

The amount of extremely corroded parts is very high due to a variety of corrosion phenomenon which occurs in the field. The position of a muffler is in a rear part of an exhaust system. It is considered as a colder part of the exhaust system as compared to the parts near to an engine. An exhaust muffler is a complex assembly of various components, performing important tasks under harsh conditions. The lifetime of a muffler is shorter as compared to any other part of the exhaust system. The major causes for premature muffler 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 are caused by fatigue [9]. Some of them are highlighted as the following:

(i) internal corrosion due to acidic condensate,

(ii) external corrosion from deicing reagents used on icy roads,

(iii) material sensitization especially on hot spots (material temperatures up to 500°C are typical for rear mufflers and 600°C for front mufflers),

(iv) static loads due to the mounting of the system and internal stresses,

(v) thermomechanical loads due to heating and cooling cycles (low-cycle fatigue),

(vi) vibrations from the engine (high-cycle fatigue).

To simulate these conditions separately, 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 lifetime 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 high temperature and aqueous corrosion with a new testing method is presented in this paper. A comparative study was performed between field systems and test systems to establish a relation for the lifetime calculation.

## 2. Experimental Discussion

There are some standard methods which are normally performed by every steel supplier and automotive exhaust manufacturing companies to screen and rank the different materials. In order to simulate the wet corrosion in exhaust components, three types of corrosion tests are usually in practice. Salt spray test to simulate the external corrosion, a well known dip-and-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 and different testing parameters. The purpose of using these accelerated corrosion testing methods is to have an insight of a product's performance in the field by simulating it in the laboratory sites. Some essential tests are explained as follows.

*2.1. Salt Spray Test.* The salt spray test is the oldest and frequently used test in an automotive industry to investigate the corrosion behaviour of various materials. This practice provides a controlled corrosive environment which has been utilized to produce relative corrosion resistance information of different materials. By adding temperature cycles, salt spray chamber can be used to replicate conditions encountered in 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 the automotive exhaust parts is that they do not accurately reproduce the conditions in which automotive parts must exist. Firstly, the parts tested in a salt-spray cabinet are continuously wet, while those parts on a vehicle experience periods of wetness and dryness. Secondly, the frequent temperature changes and presence of salts other than sodium chloride in the real-world conditions differ from the conditions in-side the salt-spray chamber. The result is that salt-spray test method produce different corrosion mechanisms and different corrosion products than the real environment.

*2.2. Dip-and-Dry Test.* The dip-and-dry test is widely used in the automotive industry [10–12] for an accelerated cyclic corrosion tests in changing wet, humid, and dry environment. This test simulates the internal corrosion in the exhaust components. Dip and dry test procedures are performed differently. All manufacturers perform these types of test according to their own experiences and specifications. There is also no standard test method available like salt-spray test for dip-and-dry test.

The concentration of condensates also varies from pH 2.0 to pH 10. Dip-and-dry tests are often criticized for unrealistic testing conditions leading to a poor correlation with in-service or the real-environment performance and also for the question on how meaningful the test data's depending on specimen to specimen and chamber to chamber variations.

*2.3. Electrochemical Investigations.* Electrochemical investigations are also used in normal routine to study the performance of a material under different conditions. These tests are the fastest available methods, where one can achieve results in a short period of time. 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 an alloy in a given environment. In general, a more positive corrosion potential means that the metal can be expected to be more corrosion resistant in that particular electrolyte than the one with a more negative corrosion potential. These tests are used to obtain instantaneous corrosion rates for making a preliminary selection for the best candidate material.

*2.4. 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) [13], MAN [14], INKA (Audi), DYKO (BMW), and Global 12W-TVACT (Ford) are well known worldwide.

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 proportion. In some cases, the conditions are very aggressive, while in the others, 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 a comparable result would lead to very high costs. Only one exhaust system could be tested during one vehicle test. Thus, to test the behaviour of various systems in one test is not possible.

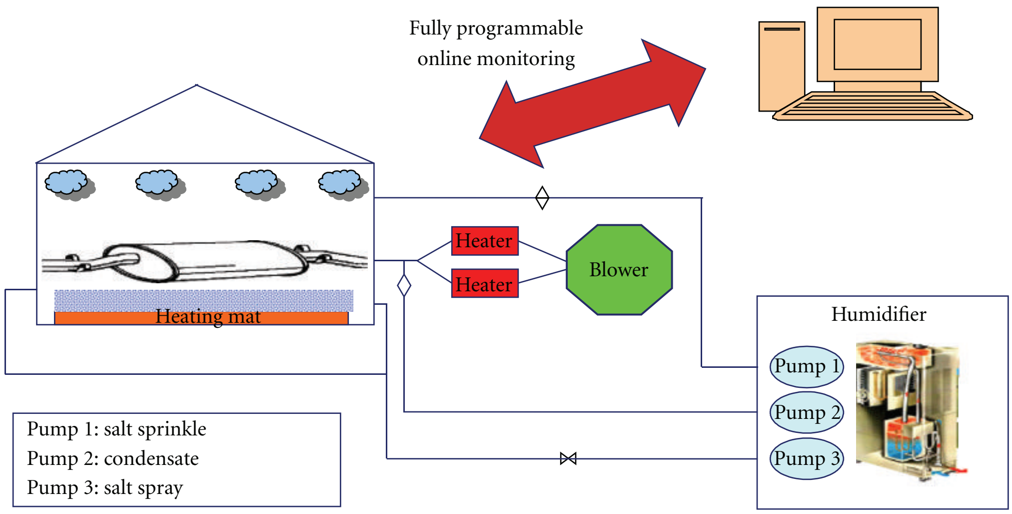
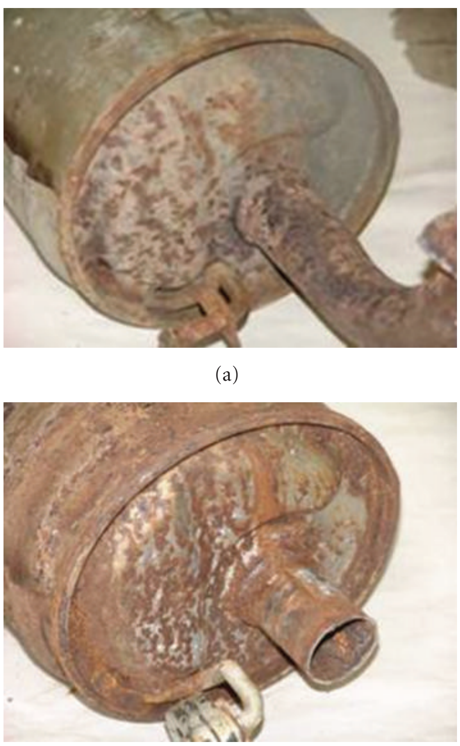


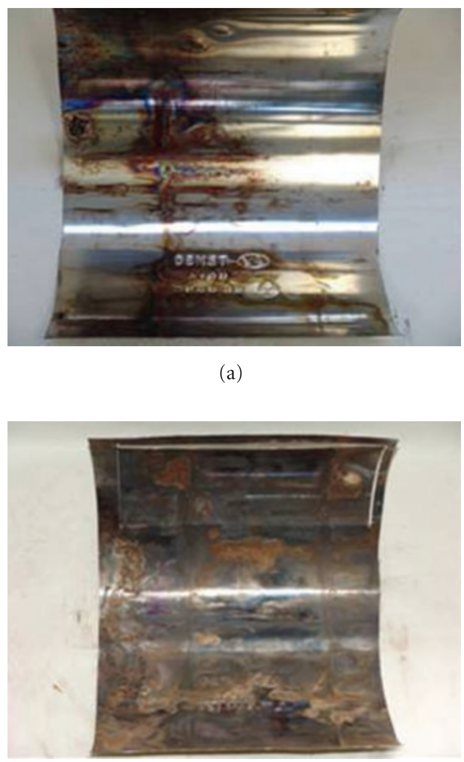

Figure 1: Layout of a test setup.



(a)

(b)

Figure 2: Comparison of field and tested system: (a) muffler from field after 54878 km/6 yrs and (b) muffler after 6 weeks of testing.



(a)

(b)

Figure 3: Comparison of field and tested system: (a) muffler from field after 54878 km/6 yrs and (b) muffler after 6 weeks of testing.

## 3. A New Component Testing Method

The concept of testing a complete system under conditions similar to the actual problem was initially proposed, and the test setup was designed (Figure 1). 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 one test was the task. A testing chamber with heaters, blowers, and pumps was constructed where the following different conditions can be programmed individually:

(a)

(b)

Figure 4: Comparison of field and tested system: (a) muffler from field after 54878 km/6 yrs and (b) muffler after 6 weeks of testing.

(i) hot gas flow with various flow rates with maximum temperature 650°C depending on the service temperature for the investigated part,

(ii) injection of an artificial condensate,

(iii) salt spray conditions with the help of different nozzles,

(iv) water or salt water sprinkling including a thermal shock effect,

(v) high humidity condition and controlled chamber temperature,

(vi) test cycles with a fully automated program.

A lifetime determination of a component with different material and design combinations was planned. The testing setup has the following features:

(i) an exact simulation of real conditions which are not possible with the standard lab tests could be done with this test,

(ii) simulation of long driving (highway type) and short driving (urban type) cycles is also possible,

(iii) all influencing factors like the role of welding, deformations and so forth. can be studied in one single test,

(iv) study of different designs and materials combinations,

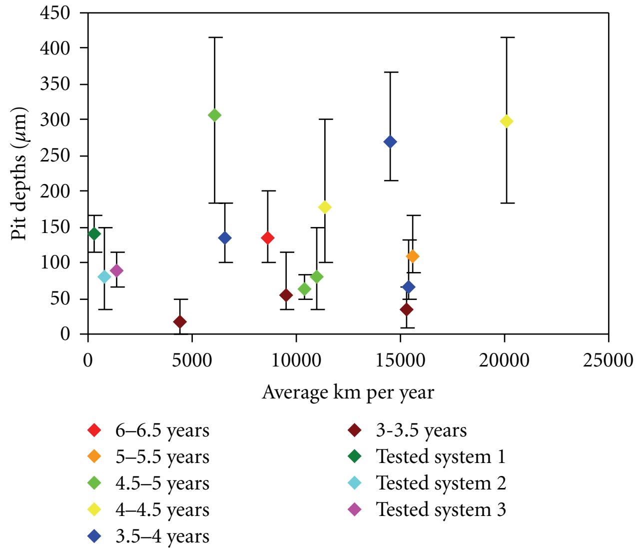



Figure 5: Comparison of all field and three tested systems.

(v) a thermal shock effect can also be simulated,

(vi) results in a very short period of time,

(vii) low cost, especially when compared to a vehicle test,

(viii) lifetime estimation of a component is possible,

(ix) enhanced reproducibility compared to other tests.

Moreover, a large field study was done on 15 parts in order to compare the behaviour of field parts and parts from the corrosion rig. Cooperation with one garage was made to obtain some corroded mufflers with some basic information for the investigation. Initially, a questionnaire sheet was provided with some important questions including type of car, mileage, number of years in field, and mode of driving (long-distance or short-distance travelling) and so forth. Then, photo documentation was done before and after cutting the systems to highlight the interesting factors like corrosion status both from outside and inside, strong and weak aspects of design, and so forth. Corrosion attack was quantified by measuring pit depths from some defined positions. Also, the same types of systems were tested in a corrosion rig to make a comparison studies. With regard to outer appearance, the corrosion rig provides a "worst case" scenario, where testing parameters were adjusted in order to simulate the desired testing conditions.

## 4. Results and Discussion

The first task was to set parameters for such test which can simulate the real conditions in a normal routine. Initially, some trial tests were done to adjust and to optimize the testing conditions. Parts from the same vehicle having the same material and design were chosen for comparative studies. Then, a direct comparison was made between some parts from field and tested parts. At first, the samples were optically compared, and then pit depth measurements were taken from the same positions.

The outer appearance of both systems showed a good relation as seen in Figure 2. The maximum corrosion attack was found at the same position in the tested system like the field parts. In Figures 3 and 4, the corrosion attack from inside can be observed. The corrosion initiation points were exactly the same as observed in the field component.

An example of pit depth measurements from the same position of all field mufflers and three tested mufflers is shown in the Figure 5. The upper error bar represents the deepest pit, and the lower error bar represents the smallest pit depth. The rhombus represents the average values. Filed systems are separated into different categories according their total life. The average kilometres per year were plotted against pit depth measurements. Field studies have revealed very scattered results for investigated systems. There was no clear relation found between corrosion progress for a given passage of time or mileage. Some other authors have also proposed this effect dependent on various other influencing factors in real life [15–17].

These results have shown a good agreement between systems form field and tested mufflers. The optical appearance of the muffler after test was quite similar to the actual parts. The aggressive corrosion attack was found on the same positions in the test like on the field parts. Some deformation on the inner sheet was also found in both cases. The results after corrosion quantification also show a good relationship between field and tested parts. Therefore, it can be concluded that with the help of this test, both material and design can be validated for a component.

## 5. Conclusions

For an accelerated corrosion test to be truly useful, a prime requirement is that the results should correlate with performance in the real world, something that has never been demonstrated with all the common routine tests. As of today, no alternative test exists which can replace all these normal routine methods. The aim of this work was to develop and optimize a new corrosion testing method for exhaust silencers. The tests were carried out in different artificial conditions. A comparative study on the tested and real parts was performed. After the completed corrosion tests, all the corroded parts have been compared by visual inspection and later by corrosion quantification on some specific positions. Obtained results indicate that the test conditions were very close to the real life. A good agreement was found between tested and real parts. This testing method with alternating wet/dry phases both from outside and inside is the most suited way to reflect the particular corrosion conditions in automotive exhaust components. The initial results have confirmed that with the help of this testing method, a lifetime estimation of the component is possible.

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