EXHAUST TRANSFER CONNECTION MATERIAL SELECTION MEETING CRITICAL QUALIFICATION REQUIREMENTS IN AUTOMOTIVE APPLICATION

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Abstract- The automotive exhaust system basically consists of a series of tubes that collect the gases at the engine and convey them to the rear of the automobile. The selection of correct material for exhaust piping design is a key step in the process because it is the crucial decision that impacts all the aspects of system life as design, simulation, manufacturability, cost and performance of the system. The requirements of exhaust system provide guidelines for transfer connection design, analysis and development. These have various critical qualification requirements including vibration, noise, durability and thermal distribution, flow and power loss, emission, in addition to its interface with vehicle. The use of stainless steel components in automotive exhaust system tubing continues to grow rapidly. This study is useful to develop an understanding of exhaust piping system material property requirement and guides towards material decision based on component functions. This paper includes the recommendations of different authors in similar systems, specifies current trends and gives guidelines for suitable tests for material selection.

Keywords- Exhaust System Material Selection, Exhaust Outlet Pipe Design, Material Property Requirement, And Exhaust Tubing Material Failure Modes

I. INTRODUCTION

Exhaust tubing materials are exposed to a variety of very harsh conditions. Materials can be exposed to temperatures ranging from ambient to as high as 800°C or even higher under some extreme conditions. A variety of chemical conditions are also encountered including exposure to alkaline and acidic exhaust condensate inside the system and to road salt on the exterior. As a result, exhaust system materials must provide not only sufficient strength and fatigue resistance but also excellent corrosion resistance under a variety of very demanding conditions.

The importance of materials selection in exhaust piping design has thus increased in recent years as the materials costs comprise 50% or more of the cost for most products. And the range of materials available to the engineer is much larger than ever before. The enormity of the decision task in materials selection is given by the fact that there are well over 100,000 engineering materials from which to choose. On a more practical level, the typical design engineer should have ready access to information on 50 to 80 materials, depending on the range of applications (Fig. 1).

The majority of the tubes and containers that comprise the exhaust system were for years made of readily formed and welded low-carbon steel, with suitable coatings for corrosion resistance. With the advent of greater emphasis on automotive quality and longer life, the material selection has moved to specially developed stainless steels with improved corrosion and creep properties. Ferritic 11% Cr alloys are used in the cold end components, with 17 to 20% Cr ferritic alloys and austenitic Cr-Ni alloys in the hot end of the system.

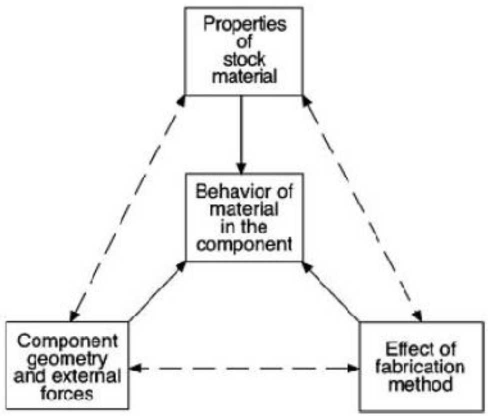

Fig. 1 - Factors to anticipate the behavior of material in the component

This paper briefs the popular exhaust tubing materials and also details their pros and cons. Recommendations are also given to ease the material decision process and guide about suitable tests being carried by OEMs.

II. REQUIREMENTS FOR TRANSFER CONNECTIONS

Exhaust transfer connection property requirements are numerous such as mechanical material property requirements of suitable rigidity to prevent excessive vibration and fatigue plus enough creep resistance to provide adequate service life. The product design specification for exhaust tubing must provide for the following functions (Fig. 2)

A. Vibration

These piping has interface with engine, body and environment. Vibration is transferred from engine to exhaust system and then transferred to body structure. The maximum vibration level at exhaust hanger point on the silencer is 30 m/sec2 for both diesel and gasoline engines and for both cars and trucks for 3G-wide open throttle max. Troque RPM condition of engine (100% load).

B. Noise

The flow of gases from engine to the exhaust will be released by the tailpipe to the environment. This produces tailpipe noise and pollution. The tailpipe noise level is important attribute to exhaust performance. The target value of exhaust system is the partial noise value contributing to the pass be noise of vehicle as mandate by Rule 120 of Central Motor Vehicles Rules (CMVR) for domestic models. The target noise value of exhaust system for both diesel and gasoline engines and for both cars and trucks is 65 dBA for idling and 90 dBA for 3G-wide open throttle max. torque RPM-condition of engine (100% load) at near exhaust (microphone at 0.5 from tail pipe at 45 degree).

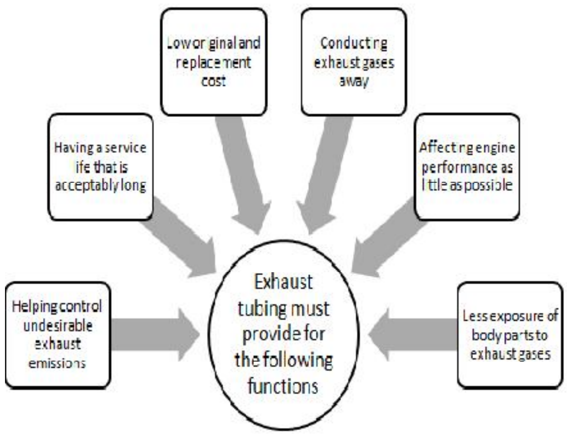

Fig. 2 - Functions of exhaust tubing

C. Durability and Thermal Distribution

The flow from engine moves in exhaust at very high temperature, especially in the hot end. For exhaust itself, the high temperature will influence material properties and thermal stress. The thermal stress will be combined with structural stress to produce high stress distribution [5]. For exhaust surroundings, the high temperature will influence the body structure. Therefore, the thermal distribution or heat management around the exhaust is another important attribute of an exhaust system.

D. Flow and Power Loss

The flow of gas in all the components is considered as turbulent flow. Thus disturbances at the wall of the exhaust tube can increase the pressure drop which in turn causes power loss. The curved and inner pipes also cause flow restriction and pressure drop, this will induce power loss [3]. The power loss will influence engine performance and therefore the exhaust power loss is a critical attribute. Flow and power loss values are targeted to be minimum.

III. AN OUTLOOK OF EXHAUST PIPING MATERIALS

Since about the mid-1990s, plain carbon and low alloy steels have been replaced by stainless steel as the primary material for exhaust systems downstream of the exhaust manifold or turbocharger. This transition has taken place because of market demands for extended warranties, and because of demands mandated by emission standards (Fig. 3). Technologies to meet increasingly stringent emission standards can raise exhaust temperatures which makes the task of meeting strength and durability requirements especially challenging

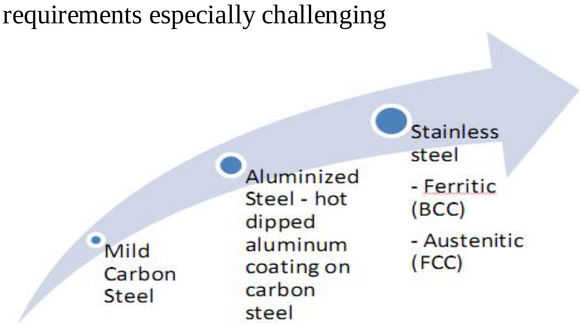

Fig. 3- Trends in Exhaust Piping Materials

1) Materials

Exhaust tubing material selection depends on numerous factors including temperature, strength requirements and chemical exposure—factors that differ depending on the exhaust system component [1]. Materials and surface protection for exhaust system should be decided as per engine and vehicle requirements. Types of material recommended for the exhaust pipings as:

- Stainless steel materials for exhaust hot end.
- Low carbon unalloyed steel, stainless steel and aluminized steel for exhaust cold end.

2) Surface Protection

Following standards can be referred for surface protection:

a) SS 8451: Surface protection (Hexavalent passivated)

b) SS 8451 S2: Surface protection (Trivalent passivated)

c) SS 7345: Heat resistance Aluminium Paints.

IV. EXHASUT TRANSFER CONNECTION VARITIES

The location of the exhaust piping under the vehicle requires that it be designed as a complex shape that will not interfere with the running gear, road clearance, or the passenger compartment. The large number of automobiles produced each year requires that the material used in exhaust systems be readily available at minimum cost.

1) Front Pipe

The front pipe should minimize heat loss for the catalyst. It also needs to have adequate high temperature oxidation resistance and resist high temperature chloride corrosion. These components are also exposed to vibration from the engine. Ferritic stainless steels are commonly used. While 409 has served well in for this component in many applications, more demanding applications often require ferritic grades such as 439 to provide adequate oxidation and corrosion resistance at higher temperatures .

2) Center Pipe

This pipe connects the aftertreatment system to the muffler. The temperature of the exhaust gas is lower and consequently, the high-temperature properties are less demanding. Common ferritic stainless steels serve well in this component for many applications. For vehicles equipped with a DPF, the temperature in this pipe may be as high as or even higher than in the front pipe during DPF regeneration, especially if an active regeneration strategy is used, and more heat resistant alloys may need to be considered. Resistance to corrosion from exhaust condensate is required at the inner surface and to corrosion from road salt at the outer surface.

V. FAILURE MODES AND APPLICATION TESTING

The function of an exhaust transfer system is not only to discharge the exhaust gas in safe manner but also to minimize the power train / exhaust vibration transferred to rest of the vehicle. Uneven exhaust gas flow results in burning, bulging and rupture of outlet wall.

Incorrect design of exhaust transfer connection may affect the engine performance, may not meet regulation requirement, may increase the tail pipe noise, transfer vibrations to other components of the vehicle, etc. (Fig. 4) important exhaust system material failure mechanisms include:

1) High temperature oxidation

One important factor determining the stability of this layer is the Pilling-Bedworth ratio R, the ratio of the volume of oxide produced and the volume of substrate metal consumed by the oxidation process:

R = (Volume of metal oxide produced) / (Volume of metal oxidized) (1) If R is less than 1, the oxide layer will be porous and non-protective (Table 1). If the ratio is equal to or moderately greater than 1, the oxide layer will be continuous and protective.

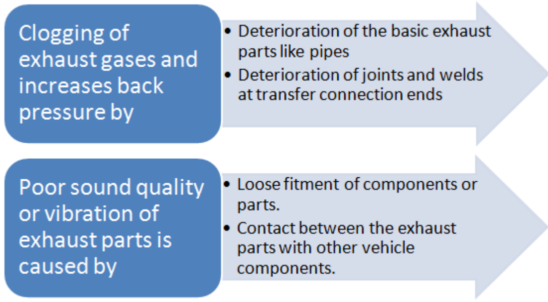

Fig. 4 – Failure effects and causes

Table 1 – Coefficients of Thermal Expansion

Material	CTE, K^{-1}
Cr_2O_3	9.6×10^{-6}
Ferritic stainless steel	$\sim 10.5\text{-}12.5 \times 10^{-6}$
Austenitic stainless steel	$\sim 17\text{-}20 \times 10^{-6}$

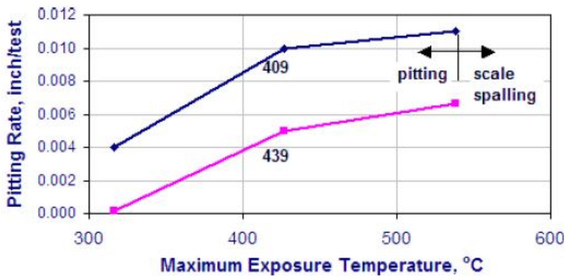

Fig. 5 - Pitting Rate After Exposure to Salt

2) Condensate and salt corrosion

As the exhaust system warms up, any ammonia contained in the condensate evaporates and changes the condensate from alkaline (pH ~ 8) to acidic (pH ~ 3). Both condensate corrosion and salt corrosion can be manifested as crevice and/or pitting corrosion (Fig. 5) in stainless steel. Exposure to salt can also significantly lower the temperature at which scale spalling occurs to 500-600°C.

3) Elevated temperature mechanical failure

Stress applied at elevated temperatures produces a continuous strain in the component, resulting in a time-dependent deformation that can eventually lead to failure. This time-dependant deformation is referred to as creep. The temperature at which the mechanical strength of an alloy becomes limited by creep rather than by yield strength is approximately 370°C for low-alloy steels, 540°C for austenitic stainless steels and 650°C for nickel-based high-temperature alloys (Table 2).

4) Stress corrosion cracking

The loss of a protective surface film can lead to the formation of a corrosion pit or trench that can lead to the initiation of a crack. Severe stress concentration, a pre-existing flaw, or a crack that formed previously by a different mechanism can also initiate the process.

5) Intergranular corrosion

Chromium can combine with carbon when exposed to temperatures from about 430 - 820°C to form chromium carbide. This is especially common in areas around welds and when components are exposed to this range of temperatures during use. This depletes the chromium available to form chromium oxide in the grain boundary regions and thus makes the metal more prone to corrosion. This effect is called "sensitization" and its extent depends mainly on the carbon content.

Table 2-Alloying elements use for failure prevention

	DOES ALLOY ELEMENT PREVENTS / MODE OF FAILURE	Chromium	Nickel	Manganese	Aluminum	Other
1	High temperature oxidation	Y	Y	Y	Y	Si
2	Condensate and salt corrosion	Y	-	Y	-	Mo
3	Elevated temperature mechanical failure	Y	-	-	Y	-
4	Stress corrosion cracking	-	N (<8%)	Y	Y	Si
5	Intergranular corrosion	N	-	-	Y	Ti, Nb

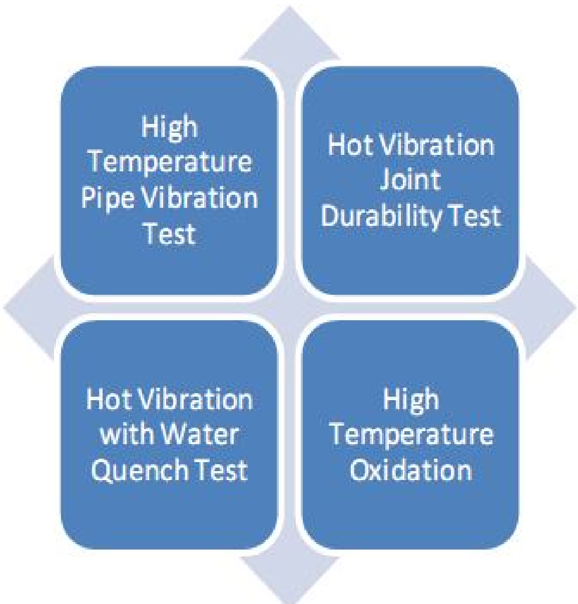

Fig. 6 – Qualification Tests for Exhaust Pipe material

These high end requirements of materials is nowadays efficiently manufactured by Powder Metallurgy process and OEMs and Tier 1 suppliers carry some specification tests to verify performance in severe conditions (Fig. 6)

VI. RECOMMENDATIONS

- Materials properties usually are formalized through standards and specifications. Following standards can be referred for material selection:

1. SS 4025: Steel sheets.
2. IS 6911: Heat resistant stainless steel plate.

- The design optimization of exhaust outlet pipe can be carried in a manner motioned in Fig. 7.

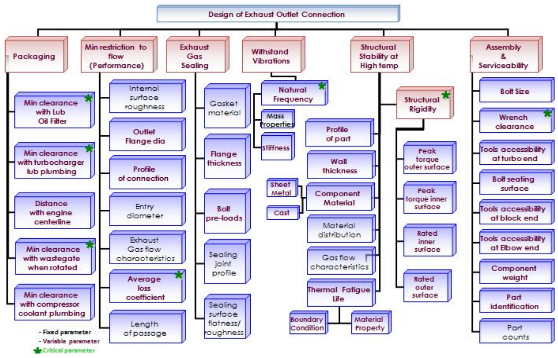

Fig. 7 - Key design parameters for exhaust system component optimization

- Aluminum alloys are often used as a coating on ferrous alloys to impart additional corrosion resistance.
- The size of the tube is determined by the volume of the exhaust gases to be carried away and the extent to which the exhaust system can be permitted to impede the flow of gases from the engine. The basic lifetime requirement is that the system must resist the attack of hot, moist exhaust gases for some specified period. In addition, the system must resist attack by the atmosphere, water, mud, and road salt (Fig. 3).
- If accessories such as exhaust brakes or turboconveyors are to be used in the exhaust system, the added restriction from these components must be considered in the design of the complete exhaust system. There are multiple aspects to be taken care of while designing a components in heavy duty vehicle exhaust line such as structural integrity against back pressure, low restriction, low vibration and other.

CONCLUSIONS

The choice of exhaust system materials is driven by a number of factors including cost, warranty requirements and legislated and customer demands for long service life. As a result, materials used in OEM exhaust systems have changed dramatically and continue to evolve.

An incorrectly chosen material can lead not only to failure of the part but also to unnecessary cost. Selecting the best material for a part involves more than selecting a material that has the properties to provide the necessary performance in service; it is also intimately connected with the processing of the material into the finished part. A poorly chosen material can add to manufacturing cost and unnecessarily increase the cost of the part. Also, the properties of the material can be changed by processing (beneficially or detrimentally), and that may affect the service performance of the part. Materials standards, which are product standards, stipulate performance characteristics, quality factors, methods of measurement, tolerances, and dimensions. This work proves to be a guideline of a schematic material selection process for exhaust transfer connection. It develops learning of the key material property aspects of such a system which undergoes severe operating conditions for large number of duty cycles. This learning can be extended in further research work on any other exhaust system component of a diesel engine.

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