

# Materials selection for automotive exhaust system engineering essay



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This assignment looks into the material selection and manufacturing process for an automotive exhaust system considering the operational requirements. Towards the end, the application of alternate material is also discussed.

### Working Requirements

The maximum temperature in an automobile exhaust system is around 750-850 degree celsius. So the selected material for manufacturing the exhaust system should be able to handle temperatures in this range. Also there are various other corrosion factors like high temperature oxidation, de-icing salt contamination and wet corrosion by condensates[mainly towards the tail pipe section].

The exhaust system can mainly be divided into 2 sections based on the working temperature. The hot end[temperatures above 600 degree Celsius] which starts from the manifold till the catalytic converter, and the cold end[temperatures below 600 degree Celsius] which extends from the pre-muffler till the tail pipe. The exhaust system is also subjected to high frequency vibrations due to exhaust gas discharge.

Normally, ferrous alloys are used in the manufacturing of exhaust system. These include carbon steel, stainless steel, alloy steels and cast iron. The purpose of adding alloying elements is to help in solid solution strengthening of ferrite, improve the corrosion resistance and other characteristics and the cause the precipitation of alloy carbides. [5]

Mild carbon steel was extensively used for the manufacturing of exhaust systems for a considerable period of time. Although mild steel has the

properties to withstand exhaust temperature it has very poor corrosion resistance. High exposure to road salt and exhaust condensate can terribly shorten the life span of a mild steel based exhaust system. Also, over the years higher demands in power and environmental safety have seen the demise of mild steel from exhaust systems. Nowadays mild steel is employed in applications where the environment is non-corrosive.

Stainless steel has replaced mild steel in exhaust systems today. The ferrous alloying element used here is chromium. The minimum amount of chromium in stainless steel is 10.5%. When stainless steel is heated, chromium forms a protective layer of chromium oxide over the stainless steel surface and delays further oxidation process.

The exhaust system in a vehicle is expected to be at its peak performance always and the material failure is a undesirable characteristic for this. Performance and efficiency of a automobile engine is seriously affected by minor changes in the exhaust system. Therefore, it is important that fail proof and efficient materials be used in the construction of automotive exhausts.

Materials used for manufacturing of exhaust systems should have the following characteristics:

High service temperature, high fatigue strength, high fracture toughness, should be easily machinable and should be economic considering the overall cost of the automobile. Also, the material should be highly resistive to corrosion as the exhaust system is majorly exposed to road salts and

condensates from the engine exhaust gases. Failure in the exhaust system  
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can cause loss of back pressure which can significantly affect engine performance parameters.[1]

### **Current trend:**

Evolution in the automobile industry has also seen the evolution of exhaust systems. From the usual carbon steel exhausts, we can see stainless steel being heavily employed in exhaust systems.

From the CES charts, we can see that stainless steel excels over low/medium carbon steel in all properties other than economy. Ferritic stainless steel is used in the manufacture of exhaust systems. Ferritic stainless steel contains chromium as the main alloying element. The percentage of chromium can vary from 10.5% to 18%. These materials are resistant to corrosion and have very low fabrication characteristics. Although, these can be improved by alloying. Grades such as 434 and 444 have improved fabrication properties. Ferritic stainless steel is always used in an annealed state as they cannot be hardened using heat treatment processes. They have very high resistance to cracking due to stress corrosion. They also exhibit acceptable welding characteristics in thin sections.[1]

We can see in detail the different parts of the exhaust system and the material properties below:

### **Exhaust Manifold:**

The exhaust manifold of a automobile engine is always exposed to hot gases. Cast iron has been in use for the production of exhaust manifolds traditionally. The main characteristics required for the exhaust manifold

material include thermal fatigue strength required to withstand the high temperature exhaust gases, oxidation resistance, good fabrication properties and low thermal capacity to enhance the catalytic function. Ferritic stainless steel exhibit all these properties and offers big weight reduction also. The developments in vacuum casting process has helped in the fabrication of stainless steel manifold with section thickness of 2-5mm. Higher demands in pollution control will rise the exhaust temperatures too and therefore, ferritic stainless steel will be in major use for exhaust system manufacturing. Ferritic stainless steel exhibits improves thermal fatigue characteristics when processed by solid solution strengthening with molybdenum or niobium. This process also improves the oxidation resistance and microstructural stability. Ferritic stainless steel also has cost advantages because of the absence of nickel in its composition. Another variant called the austenite stainless steel is used where ferritic stainless steel is unsuitable. Austenite stainless steel can enhance its properties when enough carbon is added to it. But, the higher cost limits its usage compared to the ferritic variant.[3]

Cast iron manifolds can be manufactured by the sand casting process. The solidification of molten cast iron can result in the formation of interstitial voids between the various particles in the cast iron structure. This can lead to particle sliding over each other and as a result a decline in the mechanical properties of the mould. Stress relieving heat treatments are performed in order to increase the dimensional stability of the material. During heat treatment, the thermal expansion of the material allows the voids to be filled. Although, care should be taken as not to overdo the heat treatment

process as too much thermal expansion can bring about more stresses in the material microstructure and this can impair material properties. Changes in microstructure can diminish material properties like thermal fatigue and fracture toughness that can result in the premature failure of the finished product.

The alternate material that can be used in exhaust manifold manufacture is ferritic stainless steel. These materials have enhanced properties for exhaust manifold production. The main feature is the low thermal expansion that is one of the major problems faced by cast iron exhaust manifolds.

Molybdenum and Niobium alloying has shown tremendous increase in the heat enhancement properties of ferritic stainless steel. Vacuum casting process that is used in the production of ferritic stainless steel manifolds is the factor that increases its cost. Effective methods need to be developed to reduce the tooling and manufacturing cost. Once this is achieved, cast iron exhaust manifolds can be replaced by stainless steel exhaust manifolds that have improved properties and weigh less and can thus adhere to stringent emission norms that come in future. Nowadays stainless steel manifolds are only used in vehicles that call for extreme performance. Commercialisation of this technology is not far away.

### **Catalytic converter:**

The catalytic converter is used to clean the exhaust gases and make it free of toxic effects. It is normally exposed to elevated temperatures like 1000 degree Celsius and therefore its durability is a very important factor in proper functioning of the exhaust system. Conventionally the catalytic

converters are made of a material called the cordierite monolith that  
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basically acts as the absorbant in it. Cordierite is a silicate and thus the component is manufactured by an extrusion process. Then it is subjected to washcoating where the monolith is submerged in materials such as  $Al_2O_3$ ,  $CeO_2$ ,  $ZrO_2$  and metals such as platinum, rhodium and palladium. The main properties of the catalytic converter monolith are as follows

Fusion point : 1450 degree Celsius

Coefficient of Thermal Expansion : 0.002 cal/s-cm-oC [low]

Thickness of monolith walls : 100 microns

Number of cells : 400-900 cpsi

The main advantages of the cordierite monolith are lower cost and manufacturing ease.

Alternate material for the catalytic converter is stainless steel. Instead of the silicate monolith metal alloy materials are used in the construction of the monolith. These metal monoliths are manufactured by the combination of flat and corrugated layers of the metal alloy. These are then made into the spiral shaped monolith. The exhaust gases escape through the channels formed between the flat and corrugated planes. Washcoating is done in this case also. But the important thing to be remembered is that this process needs to be done before the monolith is made into a spiral shape. This is because the metal monolith is generally smaller in size and that can obstruct the proper washcoating of the entire metallic monolith. The main characteristics of the metallic monolith are as follows:

Fusion point : 1600 degree Celsius [150 degree Celsius more than cordierite]

Coefficient of Thermal Expansion : very high [directly influenced by aluminium content in metal alloy]

Thickness of monolith walls : 25 microns [less compared to cordierite]

Number of cells : 800-1250 cpsi

[2]

One of the major advantages of the metallic monolith is the high impact resistance. As the catalytic converter is prone to impacts from road surfaces, it is important that the catalytic converter remains intact at all times. The cordierite monolith is very weak compared to metallic monolith in this case. Metallic monoliths also have the advantage of being placed close to the exhaust manifold. This means that they can achieve the operating temperature [around 300 degree Celsius] earlier and thus reduce exhaust contamination. These monoliths can also be developed in smaller sizes compared to the silicate counterparts. Higher service temperature means that metallic monoliths are used in high performance applications where the conditions are very severe.

### **Muffler :**

The muffler is the final part in the exhaust system. The introduction of catalytic converter has led to the formation of condensates inside the muffler thereby resulting in corrosion. Aluminized carbon steel is employed in the manufacture of the exhaust mufflers traditionally. The exhaust gas



condensates have amplified the corrosion rates in the muffler and it is seen that they do not perform to their maximum service life when the catalytic converter is introduced. This normally happens in the short runs of the vehicle where the exhaust gas temperature does not rise high enough to vaporize these condensates. During long runs, the exhaust gas temperature goes over 100 degree Celsius which prevents the formation of condensates and reduces corrosion. Stainless steel mufflers have very high corrosion resistance and the addition of chromium and molybdenum can improve these properties. High production rates can be achieved by the use of stainless steel by tandem mill cold rolling, annealing and descaling process. Titanium can also be added in small traces to improve muffler properties in stainless steel.[3]

### **Titanium exhaust systems [ a future perspective]:**

Environmental agencies now prefer guaranteed corrosion resistance on exhaust systems for more than 100, 000 miles. Titanium achieves this and is much better than stainless steel systems that are used now. A typical catalytic converter and muffler pipe in stainless steel weighs around 10kg. A redesigned titanium system weighs only around 3. 2 kg. This weight saving is very beneficial when considering high performance and high precision automobiles.

Pure titanium tube and sheet are the materials of choice for silencers, and pipes. Reduction of weight and cost are achieved by selecting the thinnest gauges of materials consistent with the engineering and acoustic parameters of the exhaust system. Titanium may not be suitable for the entire system, and will most probably be limited to components in which the temperature of <https://assignbuster.com/materials-selection-for-automotive-exhaust-system-engineering-essay/>

metal does not go over 400 degree celsius for longer periods of time. The parts immediately behind the catalytic converter continue to perform well under test. Use of titanium lugs welded to the pipe will certainly prove to be the most efficient method to fix the exhaust to the vehicle frame (via rubber isolators).

Material conforming to ASTM Grade 2, (e. g. Timetal 50A) offers the optimum in terms of cost, availability, fabricability, weldability and mechanical properties. Grade 45A is slightly less strong and more ductile than 50A and may be required where extensive forming is part of the manufacturing process e. g. lock seaming (Table 4). Both alloys are fully weldable, require no intermediate or post-forming heat treatment, and are available in wide sheet coil. These alloys are also used to manufacture low-cost continuously welded tube.

Properties of pure titanium 45A and 50A

## **45A**

## **50A**

Thermal expansion (10-6degree Celsius)

8. 9

8. 9

Hardness (HV)

140-170

160-200

Tensile Modulus ( 103N. mm<sup>2</sup>)

103

103

Density ( g. cm<sup>-3</sup>)

4. 51

4. 51

Specific Heat( J. kg<sup>-1</sup>. oC<sup>-1</sup>)

519

519

RA min (%)

40

35

### **Titanium Production:**

Pure titanium is cold formable, and sheets or tube can be shaped readily at room temperature using techniques and equipment that are normally for steel. Following factors must be taken into consideration while machining titanium.

- The ductility of titanium is generally less than that of steel. More generous bend radii may be required during bending applications.
- The modulus of elasticity of titanium is about half that of steel. This means that titanium will return back to original state after forming. Compensation for this can be done by slight overforming.
- Titanium tends to gall against unlubricated forming tools. Proper lubrication of the tool can solve this problem.

Both lock seaming and resistance welding are suitable to join the catalytic converter, and traditional TIG is suitable to seal the ends and pipe joints with a torch trailing shield to the external surface of the box end joints.

### **Production Economy:**

A leading exhaust system manufacturer in the United States, successfully rolled and seam welded a batch of titanium boxes at one of its production units. This was done with no extra cost when compared with the production of steel components. It was also seen that the bending units that are currently employed for the bending of steel are suitable in the case of titanium also. The only factor is the procurement cost of titanium and therefore significant efforts are necessary to bring down tooling and manufacturing costs.[3]

### **Conclusion:**

It can be concluded that stainless steel can replace conventional materials in automotive exhaust systems. We have to count on developments in tooling and manufacturing methods that can bring down overall costs to minimum.

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Stainless steel is easily the best alternative in service aspects of the exhaust system. High performance materials like titanium may also come into commercial production soon. Improved thermal, mechanical and chemical properties are major factors that govern material selection for an exhaust system.