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# Exhaust Manifold

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## ABSTRACT

This report deals with macrostructural changes depending on the manufacturing route for a selected component. Explanation is carried out on selection of advanced material as an alternative material for the same component and explained its advantages and disadvantages as a component and a manufacturing route has been suggested for manufacturing the component using that advanced material. Present manufacturing routes were discussed for the component on a big batch size.



## 1. Introduction

Depending on the in service conditions for an exhaust manifold and silencer different conventional materials were sorted and finally obtained are ductile cast iron and mild steel as respective materials. Few techniques and particular characteristics that influence manufacturing routes were explained and present manufacturing scenario has discussed. Selection of advanced material as an alternative material influenced a lot on both component properties and type of manufacturing route.

## 2.Conventional material's manufacturing options

### 2.1 For Exhaust Manifold's material

The material selected for making exhaust manifold was cast iron ductile from CES based on in-service conditions. For manufacturing a part like exhaust manifold which has 3D hallow shape with cast iron ductile, mainly investment casting and sand casting comes into view. Cast iron ductile can be made into exhaust manifold in both of the casting processes easily.

| Categories | investment | Sand casting |
|---|---|---|
| Shape | Simple-complex | Simple-complex |
| Mass range | .001-100 | .01-1000 |
| Thickness range | 1-75 | 3-999 |
| Tolerance | .01-025 | .8-3 |
| Surface roughness | smooth | rough |
| Relative tooling cost | low | low |
| Equipment cost | medium | low |
| Labour intensity | High | high |
| Mould materials | Cannot recycled | Cannot recycled |

Table (2.1.1) Comparison between different castings

For a large batch size separate surface finishing process impacts more cost, for this situation investment casting is most preferable because in this type of casting part surface is smooth when compared to sand casting as shown in table(2.1.1)

2.2 For Silencer's material

According to the service conditions of silencer, mild steel was chosen as a body (skin) material with few surface treatments. Silencer body manufacturing can be done in investment casting or deformation process. Rather than casting mild steel into a silencer's body it is better to make sheet forming because of poor hardenability as the percentage of carbon in mild steel is low. In deformation process, cylindrical rolling can be done to produce sheets and press working process and then welded to attach ends.

## 3. Manufacturing route for exhaust manifold

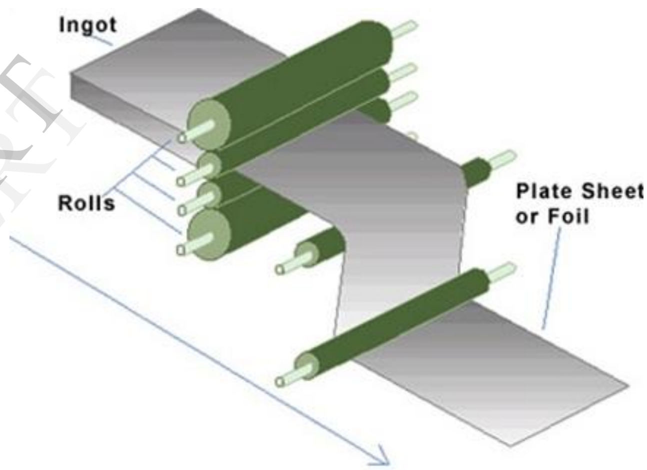
The current manufacturing process for exhaust manifold by convert mould investment process. This process add more advantages to the part by preventing hot tears, vacuum assisted pouring, less chance of defects due to moulding, and greater casting yield. Wax pattern will be made and dipped into organic sand to create moulding. The organic moulds are converted into ceramic moulds by dipping in binder comprised of silicate and alkaline components compounded in alcohol solution. A new organo-silica compound will be formed after drying and hydrolysed. When the compound is heated to 900$^{0}$C tridymite is formed.

Fig(3.1) Mould tree assembly

Molten metal at temperature of 1500$^{0}$C then poured into the mould as shown in fig(3.1), at this time ceramic moulding helps in solidifying the metal even in thin sections. Due to simple gates as no much turbulence will be seen from the advantage of mould metal wastage is also reduced which is considerable point when batch size increases.(R.K JAIN, 2008)

## 4. Manufacturing route for Silencer

Manufacturing route like deformation process for such simple shaped parts in more batch size considerably involves low capital and maintenance cost when compared to investment casting. The route starts with cold rolling of material. This process is done below re-crystallisation temperature in order to increase yield strength and surface finish characteristics. The feed of metal in rolling is around 10mm/sec and roll surface speed may be around 2000mm/sec (R.K JAIN, 2008) rolling is done resulting in hall petch hardening due to temperature raise during rolling.




Fig(4.1) Animation of Roll forming process

These metal sheets are then cut into desired shapes and sizes after proper annealing is done. Then the cut work piece is subjected to power press process for which the desired shapes are needed. A die will be clamped to a ram where the sheet will be pressed to attain the shape. After this process edge folding process is done as during power press process, edge of sheet will slightly shear. During the edge folding process, a beam raises and folds the sheet around bend profile. After completion of edge folding process, submerged arc welding process is carried out to join edges. In this automated welding process E6013 wire is used to weld the joints and weld bead is layered at a

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distance of 2.5mm which finally gives a crack resistant joint.

## 5. Micro structure changes in material due to manufacturing process

### 5.1 For Cast Iron ductile

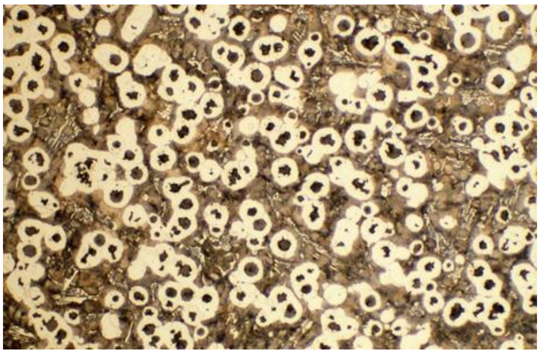


Fig (5.1.1) Microstructure of cast iron ductile

As casting is done above melting point various macrostructural changes will happen. The dark coloured circular parts are graphite nodules and matrix white is light in colour when compared to graphite nodules are called as pearlite as shown in fig (5.1.1). Pearlite is a combination of ferrite and iron carbide. During solidification precipitation phase is seen in austenite which has a carbon concentration of 2wt%. During casting at eutectoid temperature austenite putrefy into pearlite. As there will be a small percentage of magnesium in the cast iron ductile graphite flakes will tend to form spheres. Sulphur content should be very low because it may effects graphite flakes to form irregular shapes. Small amount of copper will give more strength to part by changing the amount of ferrite and pearlite in matrix. When annealing is done hardness will be attained by the formation of martensite. (ductilecastiron,2007)

### 5.2 For mild steel

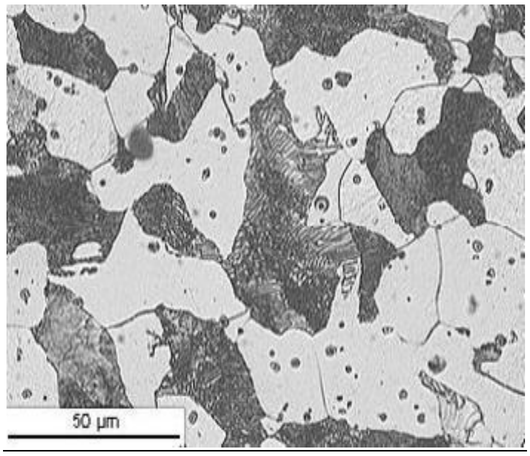



Fig (5.2.1) Microstructure of mild steel

The microstructure of mild steel contains 0.2% of carbon when alloyed with iron. Pale coloured region in the fig (5.2.1) is ferrite. Dark parts are called pearlite. The amount of pearlite in mild steel is about 25%. The wormy texture is made up fine ferrite and iron carbide. The inclusions of oxides can be clearly seen on ferrite. In rolling as the systematic grain distribution is seen, this decreases amount of pearlite for which the part's toughness and strength will be increased. The percentages of inclusions are also avoided due to cold rolling for which ductile fractures are minimized. Non metallic inclusions in the material due to metal manufacturing defect gets elongated due to rolling and forms inclusions which leads to failure which the part is under loading. As rolling is done below recrystalisation temperature slow cooling process will be seen and as a result after process ferrite present will be soft and ductile and cementite constituent becomes brittle.

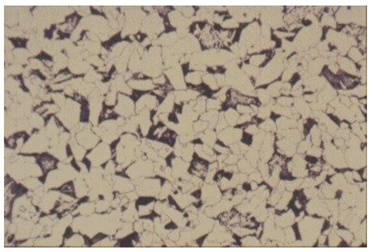


Fig (5.2.2) Microstructure after rolling of mild steel.

In the fig (5.2.2) shows the microstructure of mild steel after rolling. Fine grain ferrite will be seen if the rolling is done below ferrite and austenite region. During welding process even though temperature is not more than the melting point cooling rate influences the formation of martensite which influences hardenability (fgg.uni, 2000).

## 6. Selection of advanced material

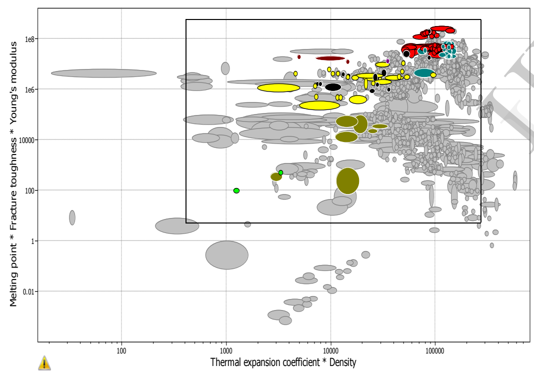
### 6.1 Selection for Exhaust Manifold

The conventional material for exhaust manifold was cast iron ductile. Due to various disadvantages like high labour intensity for manufacturing, low thermal fatigue strength for the part which are made by cast iron ductile, CES is used to determine an alternate material to improve different characteristics of exhaust manifold.

<u>6.1.1Material indices</u>

(E*ktc*Tm)/ (α*ρ)

Maximum service temperature is very important characteristic for a material for using as an exhaust manifold. The range of maximum service temperature is 900$^{o}$C to 1200$^{o}$C. This limit has added in selection of material. On applying material indices in CES a list of materials were shown as shown in graph(6.1.2)




Fig(6.1.2) List of materials after applying limits

in maximum service temperature

Another graph has plotted between maximum service temperature and price to attain alternative material optimally satisfying both scales. The following graph (6.1.3) shows the choice of materials available.

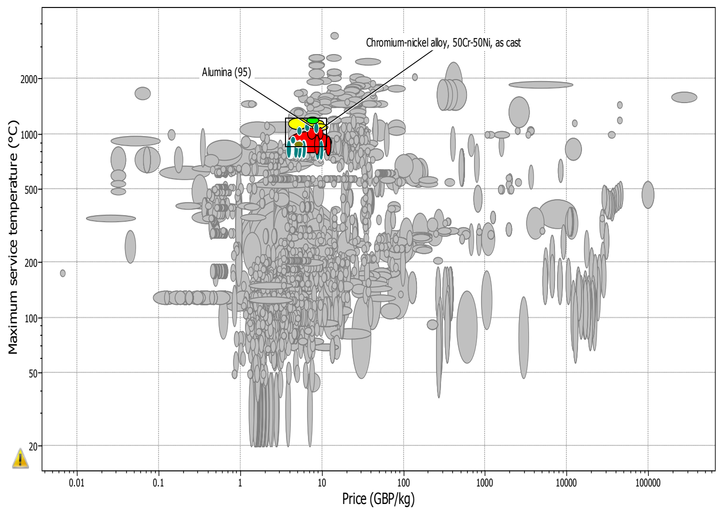



Fig (6.1.3) final selection of material from available materials

Upon all materials, chromium nickel alloy seems to be optimal when a chart is made between present stainless steel and chromium-nickel alloy.

### 6.1.4 Advanced Material benefits and disadvantages

<u>Benefits of Exhaust manifold due to advanced material</u>

- High corrosive resistant to burnt gases
- Good wear resistance
- Coefficient of thermal expansion is low
- Good oxidation resistance due to presence of nickel in alloy

<u>Disadvantages of Exhaust manifold's advanced material</u>

- As it is an alloy it start to lose strength at eutectic temperature, because it is the temp where individual parts of the alloys commence to soften
- Material cost is more when compared to stainless steels

### 6.2 Selection for silencer

For selecting alternate material in-service conditions of silencer are noted and a material index is made. As hot gases enter exhaust silencer at 148$^{o}$C, the maximum service temperature should be around 150$^{o}$C to 500$^{o}$C. On applying this limit and material index the following graph (6.2.1) has displayed.

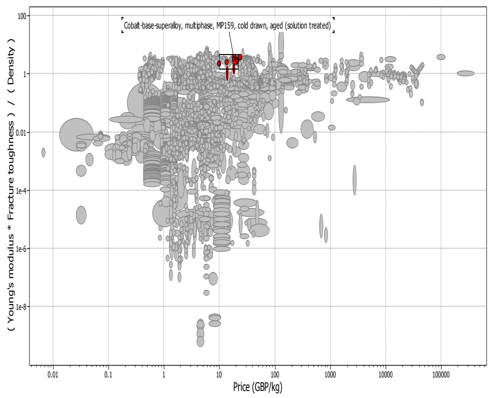



Fig (6.2.1) Graph for available advanced material

Cobalt base superalloy is one of the optimal materials highlighted in the graph. There are other materials that are shown but, those are not for automotive purpose. This material has reasonable corrosive resistance and has good resistance from environmental wear.

<u>Benefits of silencer due to advanced material</u>

- high fatigue strength
- high corrosive resistance
- Increased life span

## 7. Manufacturing route for Exhaust Manifold using Chromium Nickel alloy

Investment casting would be ideal for making exhaust manifold from Cobalt Nickel alloy. Unique aluminium mould will be prepared as the desired shape of exhaust manifold and then molten wax will be injected into it. Here the aluminium mould will have few moving parts as the manifold is hollow shaped which helps wax pattern from damage while removing from mould. After removing from mould sprues and excess wax will be removed. These wax patterns will be attached to the central runner which is also made of wax and attached to ceramic cone at one end and on whole is called pattern tree. Now the wax assembly will be dipped in ceramic slurry and then rotated in ceramic stucco in continuous intervals. On applying few coatings of zircon based refractory and silica sol binding, a thick ceramic mould will be formed to sustain thermal stresses as molten metal enters at around 1500$^{o}$C (Rajput R.K 2007). The hallow cavity should be made by removing the wax from the ceramic mould. For this the assembly will be kept in a steam vessel where superheated steam will melt and comes out of the shell. This process takes around 10mins depending on the shape and size of the mould.

The melted wax will be re used as main runner for next assembly. After removing wax the ceramic shell will be heated to 1000$^{o}$C to remove left over wax which increases mechanical strength.

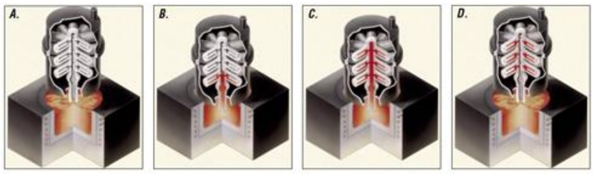



Fig (7.1) Molten metal entering stages

Unlike gravity pouring, counter gravity process using vacuum is more feasible for such alloy. Here the mould is kept in a vacuum chamber with an open pipe for which air suction will be done. Now the chamber will be inserted into the molten metal furnace where molten metal will be kept at 55$^{o}$C above its melting point for proper flow into the mould. Creation of vacuum starts molten metal to enter into moulds as shown in fig (7.1). After solidification of metal in the moulds, the ceramic material can be removed by vibrations, shooting high pressure water, or dissolution in chemicals depending upon the type of binder used for moulding. Sprues and small amount of flash will be removed from the casting by disc cutters which are high in abrasive strength. Heat treatment should be done for homogeneous distribution of structure and even increases machinability.



## 8. Manufacturing route for Exhaust silencer with Cobalt based supper alloy

For manufacturing a silencer with cobalt based super alloy processes of forming by press and explosion is very optimal when compared to electromagnetic forming. The output part has very small diameter and even shape is also simple regular cross-section for which press forming is highly preferable. Hot rolling is by far the most popular and well known technology to produce rolled section any material, this process is very beneficial in attaining desired shape, mechanical properties, and the surface finish and is also cost

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effective manufacturing method. The hot shape rolling involves passing the material through a series of shaped roll as shown in fig (8.1). Before the material is fed into the rolling mill the material is heated to up to 0.8 Tm. Generally a round or round cornered square billet or slab is rolled in several passes into desired shapes. If the raw materials are a product of single piece casting the end product would be improved even more.

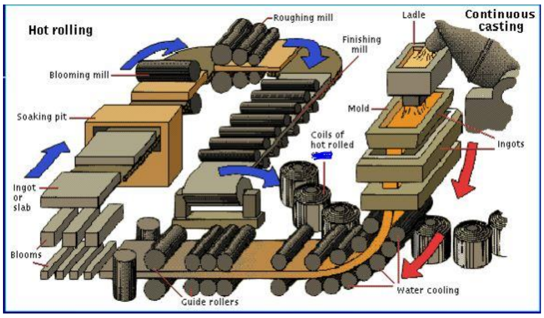


Fig (8.1)Hot rolling process

The signature of the hot rolling is not crystallized structure but a simultaneous rate of dislocation propagation and softening process but the important properties depend on temperature and grain size. There are several advantages of hot rolling

Flow stress are low, hence there is less requirement of power and forces. And even large work pieces can be deformed with equipment of reasonable size. Ductility is high so large deformation can be taken. Complex parts can be generated. The upper limit of the hot roll is determined by the temperature at which either melting or oxidation occurs. (M.P.Groover, 1999)



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