International Journal of Emerging Engineering Research and Technology
Volume 7, Issue 8, 2019, PP 20-27
ISSN 2349-4395 (Print) & ISSN 2349-4409 (Online)

# Analysis of Critical Properties Suitable for the Selection of Material for Exhaust Manifold, Muffler Box and Tail Pipe

**P.O. Satope[1], E.K. Orhorhoro[2*], I.S. Anisha[3]**

[1]*Department of Mechanical Engineering, Coventry University, Priory Street, CV15FB, West Midlands, UK*
[2]*Department of Mechanical Engineering, Igbinedion University, Okada, Nigeria*
[3]*Department of Welding Engineering and Offshore Technology, Petroleum Training Institute, Effurun, Nigeria*

***Corresponding Author:** E.K. Orhorhoro, Department of Mechanical Engineering, Igbinedion University, Okada, Nigeria, Email: ejiroghene.orhorhoro@iuokada.edu.ng*

## ABSTRACT

*The exhaust system defines a significant portion of the engine structure. The state in which the exhaust system fluctuates between makes it important to ensure that it does not fail due to material incapability. This research work is focused on the analysis of critical properties for the selection of material for exhaust manifold, muffler box and tail pipe. The material properties such as high melting point, high service temperature, low thermal expansion co-efficient, fracture toughness greater than 15MPa.m1/2 , high fatigue strength, and reduced weight that are critical for the selection of material for the exhaust manifold, muffler box and tail pipe were evaluated. The properties were used in selection of material focusing more on alloys and ceramics that can perform better in terms of overall requirement to the conventional materials being used. The required material properties for the components were used to limit the database of the CES Edu Pack 2015 to obtain advance materials instead of conventional material used in such application. By using related material selection indices, stainless steel, martensitic, AISI 414L, wrought, annealed were considered suitable for the design of muffler and tail pipe, while Titanium, beta alloy, Ti-15Mo-3Al-3Nb, duplex aged was found suitable for the production of exhaust manifold.*

**Keywords:** *Exhaust manifold, muffler box, tail pipe, critical properties, material selection indices*

## INTRODUCTION

The exhaust system is an essential part of the automobile engine. Automobile exhaust systems are essential parts of the overall chain of functions in an automotive system. The importance of exhaust systems has evolved to cover various functional processes in an automobile. Owing to this revolution, material selection prior to production of automotive exhaust systems has been very crucial [1-2]. It functions to attenuate the dangerous effect of exhaust gases on the environment and also reduce engine noise during performance. The operating temperature divides exhaust system into both hot and cold ends. Three major components in an exhaust system are the exhaust manifold, the muffler and the tail pipe. Materials used in the design of various components of the exhaust system are selected based on the intended functionality and efficiency. The state in which the exhaust system fluctuates between makes it important to ensure that it does not fail due to material incapability. With government enforcing strict regulations on issues of exhaust gases (higher combustion temperature in the cylinders), and supporting value-added fuel consumption and higher corrosion resistance in automobiles, the study of materials used in the design of exhaust system is a necessity [3-5].

The evolution of functioning systems in automobile exhaust, advances in technology and material science have made remarkable significance in the production of the best materials and designs for automobile exhaust systems. As regards material selection and design, there are many factors that must be put into consideration [6-7]. To select the materials for exhaust manifold, the muffler as well as the tail pipe using CES 2015, various material indices were used. The loading conditions of each of the components of the exhaust system were transformed into different material indices for material selection in CES 2015. Various material properties such as maximum service temperature, fracture toughness as well as oxidation level required were used to limit the CES Edu Pack database before various material property plots were obtained.

## Research Methodology

To select the materials for exhaust manifold, the muffler as well as the tail pipe using CES 2015, various material indices were used. The three major components in an exhaust system are the exhaust manifold, the muffler and the tail pipe. Materials used in the design of various components of the exhaust system are selected based on the intended functionality and efficiency. The loading conditions of each of the components exhaust system was transformed into different material indices for material selection in CES 2015. Various material properties such as maximum service temperature, fracture toughness as well as oxidation level required were used to limit the CES Edu Pack database before various material property plots were obtained.For each part of the exhaust system, different materials were selected. A thorough material selection process at level 3 and level 2 of CES 2015 gave stainless steel, especially “stainless steel, austenitic, AISI 201, wrought, ¾hard” for exhaust manifold. Low carbon steel especially “high strength low alloy steel, YS300 (cold rolled)” was considered suitable for the manufacture of the muffler and tail pipe. Each material can be produced from variety of manufacturing processes.

### Exhaust Manifold

When the selection was made at level 2, Tungsten alloys, Stainless steel, Nickel-chromium alloys, and Nickel-based super alloys were the materials available for selection. Each of these materials can take varied manufacturing route. Limiting the material to “Stainless steel, austenitic, AISI 201, wrought, annealed” meant that casting is eliminated from the manufacturing route available for producing the exhaust manifold. This is made obvious by the material property card in CES 2015 that highlights casting as process that is unsuitable as shown in Figure1.

| Processing properties | | | | |
|---|---|---|---|---|
| Metal casting | Unsuitable | | | |
| Metal cold forming | Acceptable | | | |
| Metal hot forming | Acceptable | | | |
| Metal press forming | Acceptable | | | |
| Metal deep drawing | Acceptable | | | |
| Machinability - speed | 25.9 | - | 30.5 | m/min |
| Weldability - MIG | Excellent | | | |
| Weldability - plasma | Excellent | | | |
| Weldability - SAW | Excellent | | | |
| Weldability - TIG | Excellent | | | |
| Brazeability | Fair | | | |
| Carbon equivalency | 4.35 | - | 5.38 | |

**Figure1.** *Material processing property for stainless steel, austenitic, AISI 201, wrought, annealed (CES, 2015)*

Considering the abundant amount of manufacturing processes available for exhaust manifold, it is important to set up a thorough selection process for the manufacturing process suitable for exhaust manifold. The selection process will be implemented on CES Edu pack to ensure compliance with international standards. CES Edu pack shows a variety of available shaping processes for stainless steel, austenitic, AISI 201, wrought, annealed material as shown in Figure2.

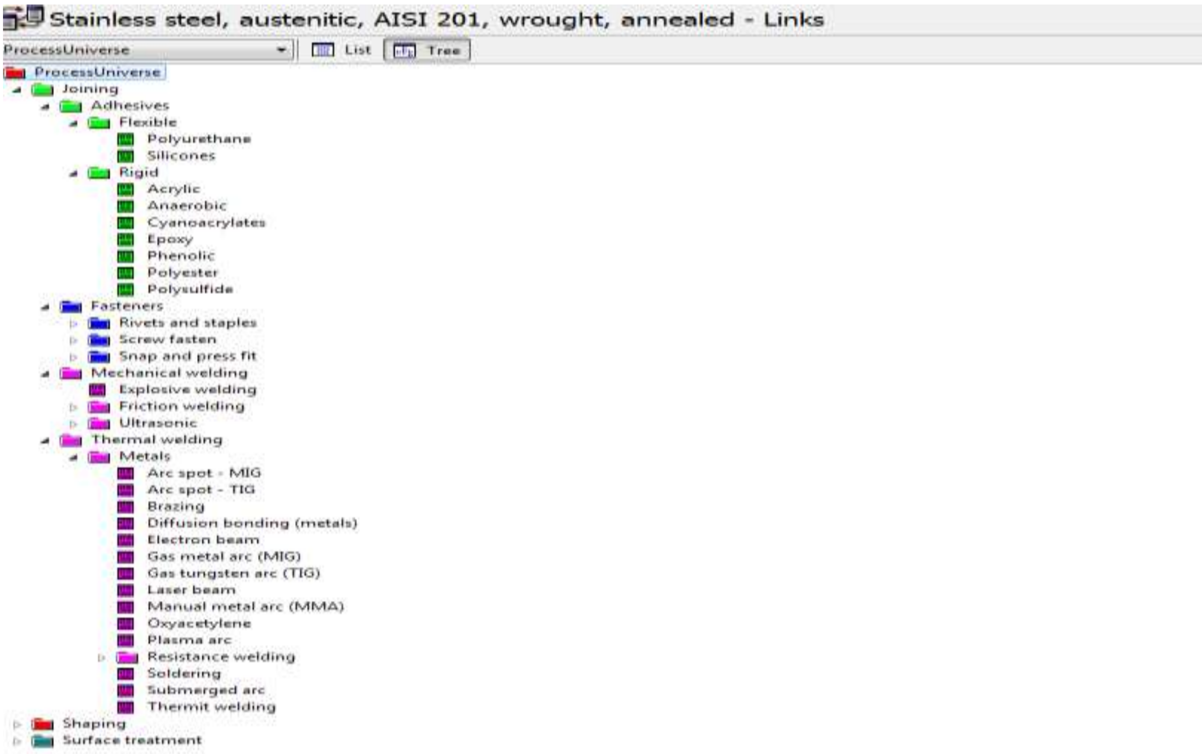


**Figure2.** *Joining Methods for Stainless steel, austenitic, AISI 201, wrought, annealed*

## Muffler Box and Tail Pipe

When the selection was made at level 2, Low carbon steel, Stainless steel, high carbon steel and medium carbon steel were the materials available for selection. These materials can take varied manufacturing route. Limiting the material to "high strength low alloy steel, YS300 (cold rolled)" meant that casting is also eliminated from the manufacturing route available for producing the Muffler Box and Tail Pipe. However, processing and manufacturing processes such as cold forming, hot forming, press forming, machining, and welding are available for "high strength low alloy steel, YS300 (cold rolled)". For muffler and tail pipe however, hot rolling and welding were used as they are conventional method used in the manufacture of the products.

## Manufacturing Route

### *Manifold*

The TIG (Tungsten Inert Gas) welding is also known as GTA (Gas tungsten Arc) in the United States and WIG (Wolfram Inert Gas) in Germany [8]. It is essentially useful in applications that require high quality welds. It is useful for variety of materials like stainless steel, aluminium and titanium. Metal fusion in Gas Tungsten Arc Welding (GTAW) is done through heating established by the aid of electric arc produced between a work piece and a non-consumable electrode. A filler metal may be required depending on variables of the kind of weld to be produced. The importance of inert gases in the welding process is huge as they are needed to shield the welding zone and the hot electrode from atmosphere [9]. The integrity of the weld in relation to the base metal cannot be over emphasized [8, 10].

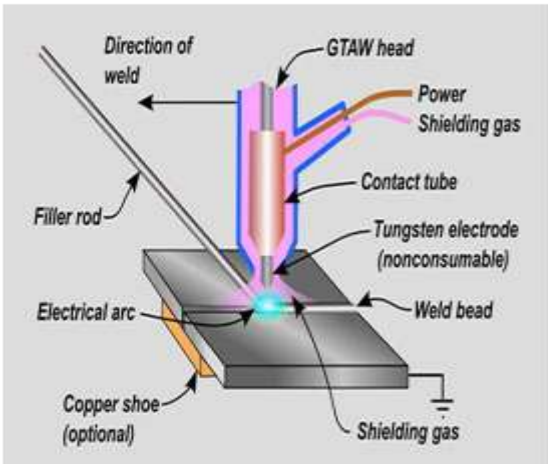


**Figure3.** *TIG Welding Process [9]*

The choice of which weld shielding gas to use is dependent on three key factors of the type of material being welded, the type of joint design and the final weld appearance required. Argon has found dominance in use as a shielding gas because of its weight and its ability to provide better shielding blanket from air than helium.

The cost of argon gives it a rather competitive edge. The fact that argon supply is easier because it can be transported in cylinder makes it a more convincing choice in TIG welding. The use of argon results in high weld quality and good appearance [8].

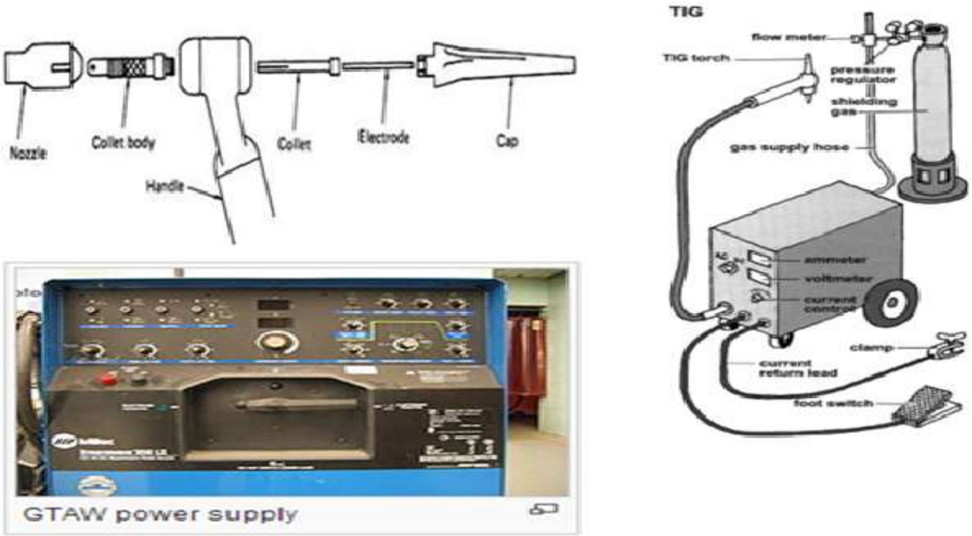


**Figure4.** *Typical TIG Welding Kit [9]*

The electrodes used in gas tungsten arc welding can either be pure tungsten or tungsten alloys and they are always colour coded. To perform a good TIG weld, the choice of electrode must be adequate [9].

### *Muffler Box and Tail Pipe*

To produce the muffler, the annealed metal sheets can be pre-heated to a desirable temperature above its re-crystallization temperature, and the pre-heated sheets, passed into rolls of desirable shapes to obtain to facing pairs of sheets that can be seam welded together to give the major part of the muffler. Pipe of desired sizes can then be processed and welded at the position to the muffler box. Cooling and chemical cleaning can be carried out to ensure the quality of the product. The various advantages of hot rolling process include low pressing force required, large work pieces can be processed due to high ductility of the material, and complex shapes can be produced with accurate dimension [11]. Roll forming is often used to produce the tail box pipe. Roll forming is a continuous process as well as a metal forming process that can generate various shapes and cross sections. Rolling is often followed by bending, cutting and sometime welding to generate complex geometry of pipes. Roll forming is a shaping method that is known for consistency and uniformity of products over a long production period unlike other shaping methods. One major advantage of roll forming for manufacturing of tail pipes is that it can process any other type of material for the same use and design. Another interesting reason for this preferred manufacturing process is that it can process pre-painted materials as well as pre-punctured metal sheets [11-12].

## Manufacturing Material Selection

### *Exhaust Manifold*

The important material properties required for the design of the exhaust manifold has been described in the initial report. Material properties like service temperature, fatigue strength, thermal fatigue life, oxidation resistance, have been listed to be important in exhaust manifold design [13-14]. The list of important properties is therefore proscribed below to include:

- Higher melting point
- High service temperature
- Low thermal expansion co-efficient.
- Fracture toughness greater than 15MPa.m1/2
- High fatigue strength
- Reduced weight

The various requirements for exhaust manifold were considered in limiting and plotting the materials at CES Edu level 3.

### *Muffler Box and Tail Pipe*

The tail pipe has requirements that are similar to the muffler as they function within the same temperature range. The operating temperature range for mufflers and tail pipes is 100oC-400oC. Creep is a major failure associated with tail pipes which often occur as a direct effect of stressed generated by hot gases impinging on the tail pipe surfaces. The list of important properties is therefore proscribed below to include:

- Lower density for weight reduction
- Low thermal expansion co-efficient.
- High stiffness
- High corrosion resistant
- Fracture toughness greater than 15MPa.m1/2
- High fatigue strength

The various requirements for muffler and tail pipe were considered in limiting and plotting the materials at CES Edu level 3.

## RESULTS AND DISCUSSION

The result of the selection process for exhaust manifold was stainless steel, especially "stainless steel, austenitic, AISI 201, wrought, ¾ hard". Low carbon steel especially "high strength low alloy steel, YS300 (cold rolled)" is however discovered to be a suitable material for the design of the muffler and tail pipe after thorough selection procedure. High strength low alloy steel, YS300 (cold rolled) is suitable for tail pipe and muffler because of its strength. The base material for high strength low alloy steel, YS300 (cold rolled) is iron. The machinability of the material is improved by traces of phosphorus while its small size in the material improves the corrosion resistance of the material. The overall strength of the material is enhanced by a trace of various other elements is small quantities. However, since the listed processes require high plasticity, annealed form of AISI 201 possess a more suitable physical state for the production of exhaust manifold compared to stainless steel, austenitic, AISI 201, wrought, ¾hard. The stainless steel, austenitic, AISI 201, wrought, annealed will therefore be considered in this report.

The graph of specific fatigue strength was plotted against stiffness; a box selection of high values of both variables was carried out. The graph of maximum service temperature compared to price was then plotted. Addition of oxidation resistant above 500oC gave clusters of titanium, Molybdenum and beryllium. With price comparism, the "Titanium, beta alloy, Ti-15Mo-3Al-3Nb, duplex aged" is the cheapest of the remaining materials and was selected as the material for the construction of the exhaust manifold. The graphs shown on Fig. 5 to 13 are a stepwise representation of the material selection procedure.

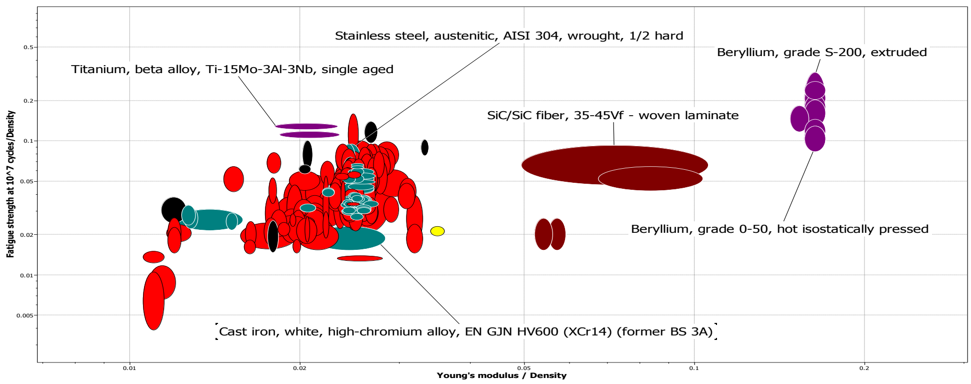


**Figure5.** *Plot of specific fatigue strength was plotted against stiffness*

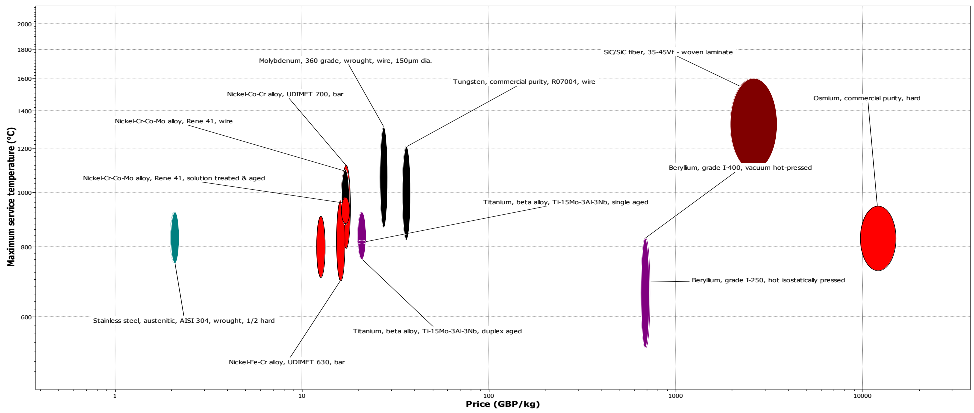


**Figure6.** *Plot of maximum service temperature compared to price*

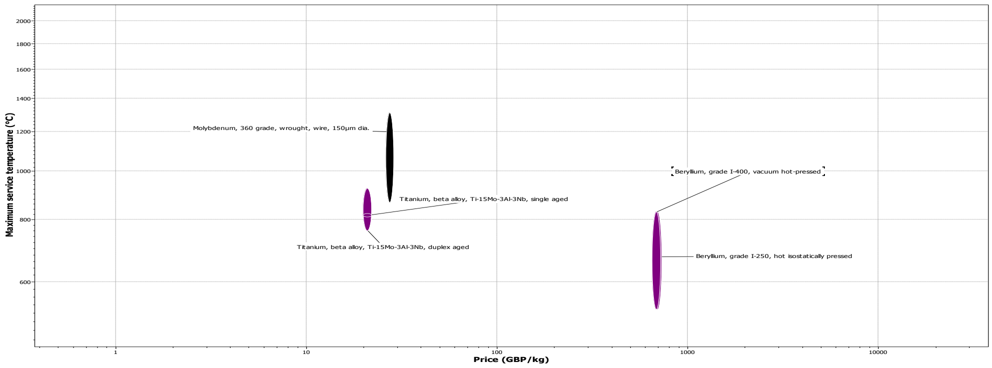


**Figure7.** *Plot of maximum service temperature against price*

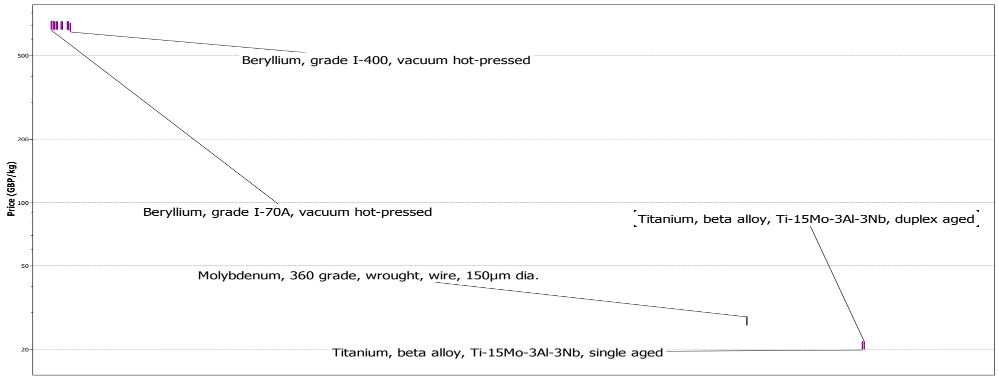


**Figure8.** *Plot of Price*

The high fatigue strength and low density of Titanium, beta alloy, Ti-15Mo-3Al-3Nb, duplex aged makes it a very good alternative for manufacture of exhaust manifold. Ti-15Mo-3Al-3Nb-0.2Si, also known as TIMETAL 21S is a meta stable beta titanium alloy that offers a unique combination of high strength, good elevated temperature properties, and extraordinary environmental degradation resistance [15]. The graph of specific fatigue strength was plotted against stiffness; a box selection of high values of both variables was carried out. The graph of fatigue strength was drawn and high values of fatigue stress were selected by box method, then the graph of young's modulus was plotted. A box selection of high values was also taken. The graph of density compared to price was then plotted with a box selection of low density and low price to ensure reduced weight. The graph gives a cluster of nickel and a cluster of stainless steel. Since most nickel materials are assumed to be toxic, it is highly unhealthy to make mufflers and tail pipes with nickel alloys. The stainless steel cluster was therefore analyzed for cost and fatigue strength. With price comparism, the "Stainless steel, martensitic, AISI 414L, wrought, annealed" is one of the cheap alternatives to the initial material. Its annealed state means that there is no need to pre-stress the material before cold work in prevention of work hardening of many austenitic stainless steel materials.

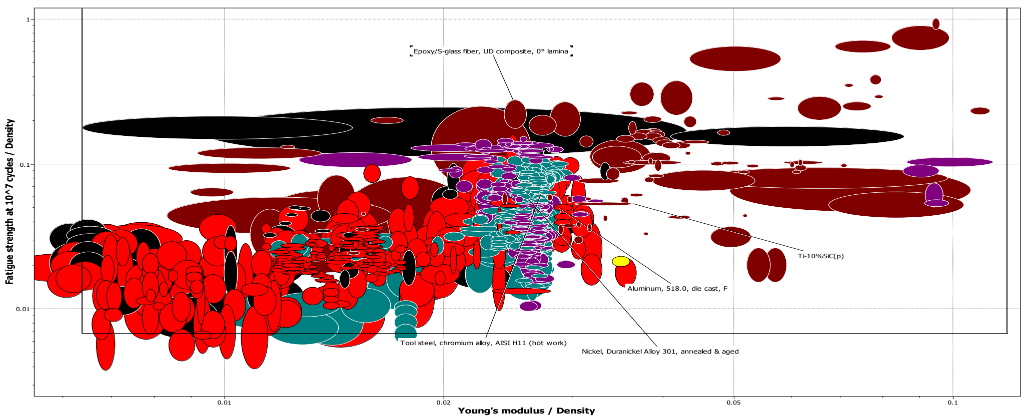


**Figure9.** *Plot of specific fatigue strength was plotted against stiffness*

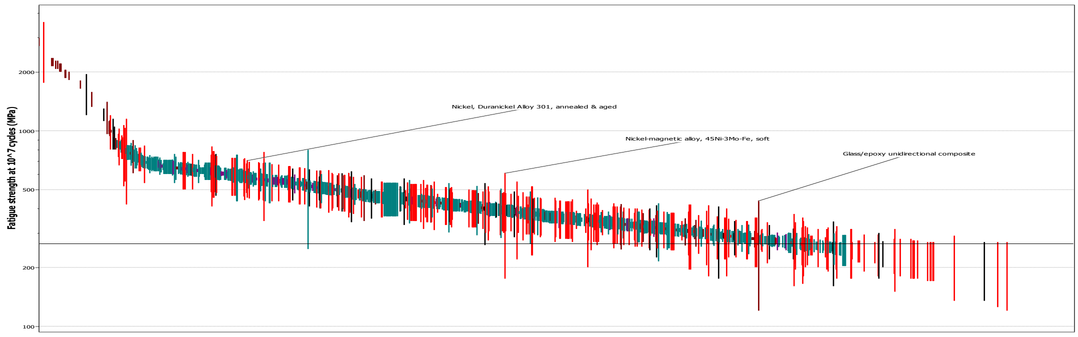


**Figure10.** *Plot of fatigue strength*

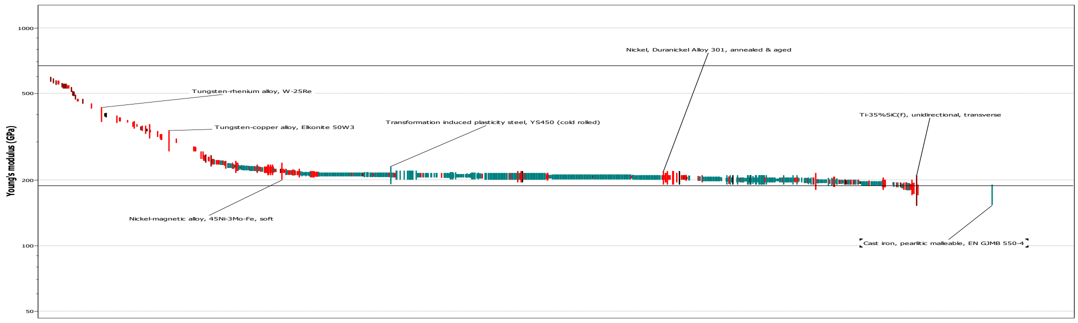


**Figure11.** *Plot of young modulus*

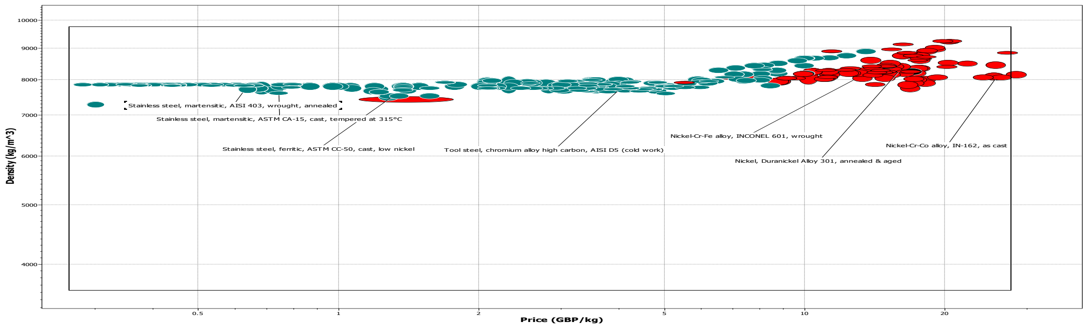


**Figure12.** *Plot of density against Price*

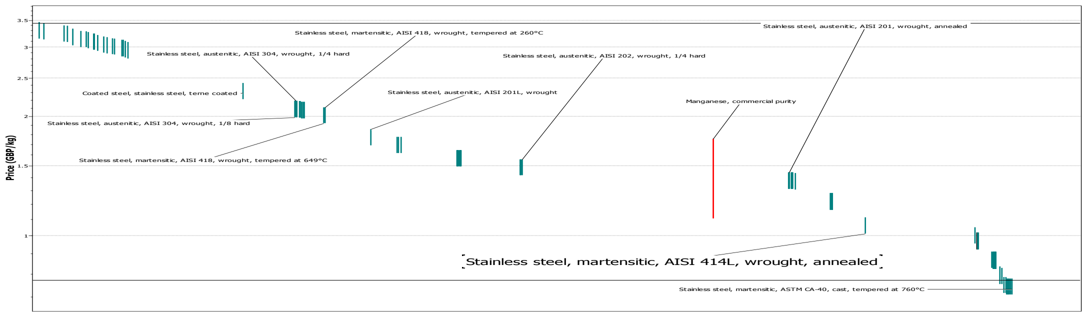


**Figure13.** *Price evaluation of stainless steel cluster*

The high resistance to corrosion of Stainless steel, martensitic, AISI 414L, wrought, annealed makes it suitable in handling exhaust gases at the muffler box and tail pipe comprehensively. Its relatively high fatigue strength makes it a very good alternative for manufacture of exhaust manifold. Stainless steel, martensitic, AISI 414L, wrought, annealed is a higher-carbon steel that contains from 11.5 to 18% chromium and may have small quantities of additional alloying elements. They are magnetic, can be hardened by heat treatment, and have high strength and moderate toughness in the hardened-and-tempered condition.

## Conclusion

This research work focus on the conventional materials and manufacturing methods for exhaust manifold, muffler box and tail pipe. By using related material selection indices, Titanium, beta alloy, Ti-15Mo-3Al-3Nb, duplex aged was found suitable for the production of exhaust manifold while Stainless steel, martensitic, AISI 414L, wrought, annealed is suitable for the design of muffler and tail pipe. Conventional investment casting was proposed for making exhaust manifold from Titanium, beta alloy, Ti-15Mo-3Al-3Nb, duplex aged while hot rolling process was selected for manufacturing muffler and tail pipe from Stainless steel, martensitic, AISI 414L, wrought, annealed.

## REFERENCES


[1] Ikpe A.E., Orhorhoro E.K, Gobir A. Engineering Material Selection for Automotive Exhaust Systems Using CES Software. International Journal of Engineering Technologies. 2017; 3(2): 50-60

[2] Inoue Y., Kikuchi M. Present and future trends of stainless steel for automotive exhaust system. *Nippon Steel Technical Report.*2003; 88.

[3] Oliver, D., Sephton, M. External corrosion resistance of steel and ferritic stainless steel exhaust systems. *Journal-South African Institute of Mining and Metallurgy*. 2013; 103(2): 93-100.

[4] ATI, Stainless Steels Type 439/AL 439 HP. ATI Allegheny Ludlum Corporation Blue Sheet Technical Data, Pittsburgh, Pennsylvania, USA, 1999.

[5] Callister W. Materials Science and Engineering. New York, John Wiley & Sons, 2007.

[6] Gaskel D. Introduction to the Thermodynamics of Materials. Taylor and Francis Publishing London SW1P 1WG, 1995.

[7] Chattha M.S., Perry J., Goss R.L., Peters C.R., Gandhi H.S. Corrosion of aluminized low carbon steel exhaust system in vehicles equipped with three-way catalytic converters and development of a protective polymeric coating, Ind. Eng. Chem. Res.. 1990; 29 (7)

[8] Wballoys. What is TIG Welding? [online] Available at: http://www.wballoys.co.uk/TIG/what-is-tig-welding.html [Accessed 8 May 2015].

[9] Fujii, H. Mechanism of A-TIG and AA-TIG (advanced A-TIG). *Welding International*. 2005; 19(12): 934-939.

[10] Groover, M. P. Fundamentals of modern manufacturing: materials, processes and systems. JOHN WILEY & SONS, INC. USA. 2010

[11] Keehan, E. Effect of microstructure on mechanical properties of high strength steel weld metals. Goteborg, Sweden: Dept. of Experimental Physics, Chalmers University of Technology and Goteborg University. 2004

[12] Callister, W.D., Rethwisch, D. Materials science and engineering: an introduction. John Wiley & Sons, Inc. Usa. 2010

[13] Faivre, L. Santacreu, P., Acher, A. A new ferritic stainless steel with improved thermo-mechanical fatigue resistance for exhaust parts. *Materials at High Temperatures*. 2013; 30(1): 36-42

[14] Guler, K., Cigdem, M. Casting Quality of Gypsum Bonded Block Investment Casting Moulds. *AMR*, 445. 2012: 349-354.


**Citation:** *E.K. Orhorhoro, P.O. Satope, I.S. Anisha, "Analysis of Critical Properties Suitable for the Selection of Material for Exhaust Manifold, Muffler Box and Tail Pipe", International Journal of Emerging Engineering Research and Technology, 7(8), 2019, pp. 20-27*