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Materials for Automotive Exhaust System

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***Abstract*— Durable exhaust system design, development and manufacturing is mandated for the vehicle to be competitive and comparative. Material selection for the exhaust system plays a vital role due to the increased warranty requirements and regulatory compliances. Physical, chemical and mechanical characteristics of the materials used for conventional and special applications are compared. Exhaust system materials should possess high temperature oxidation resistance, thermo mechanical vibration resistance, external salt corrosion resistance and internal acid/base corrosion resistances. Internal components such as inner cones, baffle plates, retainer rings, perforated pipes and external components such as hanger rod, outer shell, heat shield, end caps outer cones, flex tube, manifold etc. should be able to withstand high thermal impact and vibrations caused by road load, thermal load and engine load. The effect of additives such as Ti, Mo, Mn and Si to the base steel material is presented. Properties of mild steel, stainless steel and aluminized steel are compared. Applications of special materials such as Inconel, FeCrAlloy, 18CrCb and A286 are discussed in detail.**

***Keywords*— Conventional, Durability, Exhaust system, High temperature applications, Material selection, Properties.**

I. INTRODUCTION

Exhaust systems are developed to control emissions and to attenuate noise vibration and harshness to meet the regulatory requirements. The exhaust system components are manifold, close coupled and underbody catalytic converters, flexible bellow, muffler, resonator, connecting pipes, flanges, and tailpipe. The part of the exhaust system containing the manifold, converter and the flex joint is named as hot end since this part of the system is relatively hot due to the hot exhaust gas passing through these components. The part consists of intermediate pipe, resonator and the muffler is named as cold end since the gas tends to cool down from the exit of the flex tube. The temperature of the hot end of the gasoline operated vehicle can be as high as 1050°Cwhile the highest temperature of the cold end is about 650°C. Material selection of an exhaust system depends on several parameters like usage temperature, geographical region and application. Depending upon the vehicle application, the material selection differs.

The materials mostly used in exhaust systems are cast iron, stainless steel, mild steel / carbon steel. Recent trends towards light weight concepts, cost reduction and better performance, designers are progressing towards sheet metals. Nowadays, stainless steels are used in flexible bellows, catalytic converter, resonators, mufflers, pipes. Mild steel / carbon steel are used for flanges, pipes, and mufflers. The addition of elements plays an important role in deciding the performance, manufacturability and self-life. Examples such as carbon increase the hardness, hardenability while reducing the ductility. Silicon increases the ductility, strength and corrosion resistance. The manganese helps in increasing the ductility, weld ability. Sulphur and phosphorous addition reduces the ductility and increases the brittleness. Molybdenum addition increases the hardenability, hardness, strength, corrosion resistance. Chromium, nickel, titanium enhances the corrosion resistance.

II. EXHAUST SYSTEM

A typical example of an exhaust system and the thermal histogram of the exhaust system for diesel and gasoline applications are illustrated in Figure 1. The material selection for the specific components is chosen to meet the service temperature of the application.

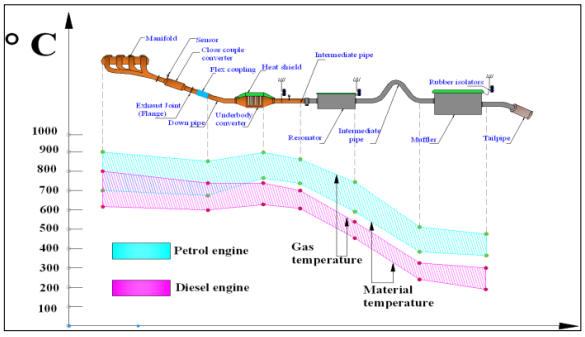

Fig1The thermal histogram of the exhaust system for diesel and gasoline applications

The functions and the commonly used materials of the exhaust system components are listed in Table 1.

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TABLE I
FUNCTIONS OF EXHAUST SYSTEM COMPONENTS

Components	Functions	Material Requirements
Manifold	Low thermal mass and durability	SUS 429LM,441L,304
Catalytic Converter	Converts toxic gases into non-toxic gases	SUS 439L,430,441L
Flexible Coupling	Withstands the vibrations coming-out from the engine and road	SUS 304,321,XM15J1
Muffler	Noise attenuation	SUH 409L,SUS 439L,SA1D
Flanges	Interlinking the exhaust system with pipes	SS400,SUH 409L
Pipes	Interlinking the exhaust system Component regulates the flow of gases.	SUH 409L, SUS 439L,SA1D
Hanger rod	Mounting the exhaust system with the chassis	S10C,STKM11A

III. MATERIALS FOR EXHAUST SYSTEM COMPONENTS

A. Manifold

Manifold is the component that collects the multiple exhaust fumes from the cylinders through the exhaust valves (which are inside the engine) and is the route which the fumes travel to the catalytic converter. The temperature at this area is high. So, a material with suitable thermal expansion co-efficient, service temperature, strength, corrosion resistance must be used here. There are two types of manifold. They are cast iron manifold, sheet metal manifold. The materials used for cast iron manifold areFCD500-SM1 and FCD550-SM1.Materials like FCD500-SM1, FCD 550-SM1 has high melting point and service temperature. They provide very good strength to withstand manifold from cracking. Low thermal mass and light weight manifolds are required for fast light-off exhaust system applications. The weldability of the sheet metal manifold is easier. The materials used for sheet metal manifold are SUS 429LM, SUS 441L, SUS 304, SUS 309.These materials provide sufficient thermal expansion co-efficient, service temperature, strength, thermal and corrosion resistance.

Fig 2 Cast iron manifold

Fig 3 Sheet metal manifold

B. Catalytic Converter Assembly

The converter assembly is responsible for emission control. The materials in this assembly converts the toxic gases in to non-toxic gases. The catalytic converter assembly consists of substrates, mat, shell and cones. There are three types of converters. The first one is the maniverter welded on the manifold. The second one is closed coupled converter which is placed at a distance between 350 and 650 mm from the engine head-face. The third one is the underbody converter placed after the flexible coupling or beyond 650 mm. The appropriate converters are selected and positioned in the exhaust system to meet the required emission norms. The materials used here should provide good thermal properties, corrosion resistance and strength.

Fig 4 Catalytic converter assembly

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1. Shell:

The converter shell holds the internals of the converter. The materials used for this shell should provide good strength, corrosion resistance and relatively low thermal deformation. The materials mostly used for the shell are SUS 439L, SUH 409L, SUS 430, SUS 432L,SUS 441L, SUS 436LM. These materials provide very good ductility, strength and corrosion resistance.

2. Substrate:

There are two types of substrates. One is ceramic and the other is metallic. Metallic substrates are used for high temperature applications. Mostly SUS 441L materials are used for metallic substrates. Metallic substrates provide higher geometric surface area with the given volume. The alternative materials used are SUS 432L, SUS 436LM, SUS 439L. High Cr and Ni containing materials such as Hastelloy, Monel, Inconel and FeCrAlloy are used for application above 1000°C. Typical examples of the metallic and ceramic substrates are shown in Figure 5 and 6.

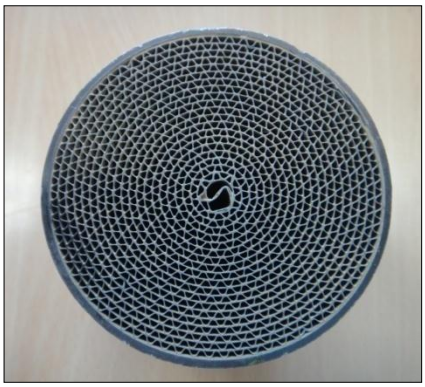

Fig 5 Metallic substrate

Fig 6 Ceramic substrate

3. Inner and Outer cone:

The inlet and outlet cones are either welded to the converter shell or formed. These cones regulate the flow of gases. The cones are designed to maintain the uniformity index of the gas flow. As cones experience high temperature, they should possess high thermal oxidation resistance. The materials used should provide the required thermal properties. The commonly used materials are SUH 409L, SUS 430, SUS 432L, SUS 436LM, SUS 439L and SUS 441L.

C. Flexible Bellow

Flex coupling in the exhaust system helps to absorb the vibrations exerted by road load, thermal load and engine load. This helps to minimize the impact of the vibrations on the exhaust system. The flexible coupling assembly consists of end cap, end cap extensions, internal liner, bellows construction, external braid. The materials used should provide strength, good corrosion resistance, ductility, bendability. The materials used for bellows are SUS 304, SUS 321, XM15J1, and SUS 316Ti. The materials used for outer braid SUS 304, SUS 316Ti. The materials used for liner are SUS 304, SUS 309, and XM15J1.The materials used for end cap, end cap extensions are SUH 409L, SUS 439L, SUS 430 and SA1D.

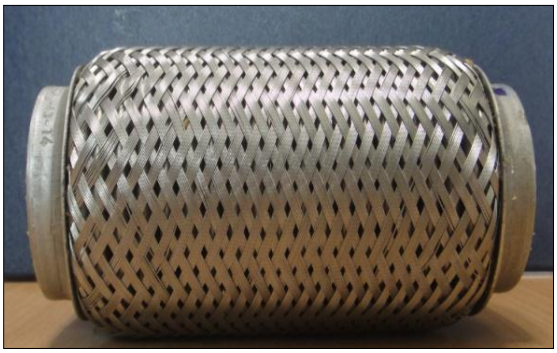

Fig 7 Flexible bellow

D. Muffler Assembly

Muffler assembly is responsible for noise, vibration and harshness reduction. The muffler assembly consists of end plates, baffle plates, perforated and non-perforated pipes, absorption material (glass wool) and shell. A representative muffler assembly is shown in figure 8.

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Fig 8 Muffler assembly

The materials used must provide good strength, corrosion resistance. The materials used for absorption material are mostly glass fiber mat, molded glass fiber mat with binder, glass fiber bulky wool (E1, E2). The materials used for these components are SUH 409L, SUS 436LM, SUS 439L, SUS 436L, SA1D, STKM 11A, SKTM 12A, SUS 436J1L, SUS 432L, SUS 429LM, SUS 441L and SUS 430J1L.

E. Flanges

Component which is used for interlinking or connecting the exhaust system with pipes. The flanges are welded with the pipes. There are solid flanges and sheet metal flanges. The spring loaded joints are used in sheet metal flanges. The solid flanges provide better strength than the sheet metal flanges. The materials used should provide very good mechanical properties. The materials commonly used for flanges are FE410, SS400, SUH 409 L, SUS 441L, SPHC, STKM 12 A and SUS 304.

Fig 9 Sheet metal flange

Fig 10 Solid flange

F. Intermediate Pipe

The intermediate pipes are used for connecting the exhaust system components. These pipes help the flow of the gas and also provide thermal management. The pipes should provide good ductility, weld ability. The materials used for the pipes in the hot end should provide good thermal requirements and corrosion resistance. The pipes used for cold end should provide good corrosion resistance. The materials normally used are SUH 409 L, SUS 430, SUS 436LM, SUS 439L, SUS 304, SUS 441 L, SKTM 11A, STZC30, STZC 52 and SUS 436L.

Fig 11Intermediate pipe

G. Hanger Rods

These components are responsible for mounting the exhaust system with the vehicle. The total weight of the exhaust system is acted on this. The stiffness and weldability of the hanger rod are very important. The materials used should provide good strength. The materials used are FE 410, SS 400, SPCC, S10C, S 20C,STKM 11A, SUS 304 , SUH 409L and SUS 441L.

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Fig 12 Hanger rod

H. Gasket

The purpose of the gasket is to avoid the leakage between two components when interconnected. The thermal stability and vibration resistance are the main factors to be considered here. The materials used are SUS 304, SUS 441L, SUS439L and SUS 409L.

Fig 13 Gasket

IV. Components For Special Application

A. Inner Inlet Cone

The inlet and outlet inner cones of the converter face high oxidation due to excess air and high temperature. A material such as 18CrCb is used to avoid oxidation of the inner cones at 900 -1050° C.

B. High Temperature Hardening Materials

Materials such as A286 are used for better spring back value during high temperature applications. A286 undergoes thermal hardening due to surface precipitation at 750°C. A286 gains about 15-20 percent compression value. Support mesh and seals are specifically made with A286 to get better mounting pressure.

C. Special Welding Materials

Welding is very critical in the exhaust system. Care should be taken during the welding of dissimilar materials. High temperature fatigue regions need special welding process and weld rod materials.

Tensile strength and yield stress of SUS 308L/SUS441combinationwelding is higher than SUS 430LNb/SUS441combination. So SUS 308L/SUS 441 weld combination is better than SUS 430LNb/SUS 441.

Physical properties of the materials, chemical composition, performance, mechanical properties such as tensile strength, elongation, hardness, corrosion resistance etc. and thermal properties of conventional and special materials are illustrated. Effect of additives such as Ni, Mo, Ti, Si, Cr etc. on base steel materials are also given in the Tables and Figures.

Table II
Material Grade Vs Mechanical Properties

Material Grade Vs Mechanical Properties								
MATERIAL GRADE	HARDNESS	HARDENABILITY	DUCTILITY	WELDABILITY	STRENGTH	CORROSION RESISTANCE	BRITTLENESS	REMARKS *
SUS 409L	↑	↔	↔	↑	↑	↔	↔	Excellent Formability,Heat resistance
SUS 432L	↑	↔	↔	↑	↑	↑	↔	High Yield strength and Hardness
SUS 439L	↑	↔	↔	↑	↑	↑	↔	High thermal conductivity, Heat resistance,low thermal expansion coefficiency
SUS 436LM	↑	↔	↔	↑	↑	↑	↔	Excellent in corrosion resistance, drawability and weldability due to the addition of Ti and Nb
SUS 430 J1L	↑	↔	↔	↑	↑	↑	↔	It has superior corrosion resistance, drawability, weldability and high temperature oxidation resistance.
SACD	↓	↔	↔	↔	↔	↓	↑	Low Tensile strength and Hardness
STAC	↓	↔	↔	↔	↔	↓	↑	Low Tensile strength and Hardness
↑ INFLUENCES			↓ OPPOSSES			↔ NEUTRAL		

Table III
Elements Vs Mechanical Properties

Elements Vs Mechanical Properties									
SL NO	ELEMENTS	HARDNESS	HARDENABILITY	DUCTILITY	WELDABILITY	STRENGTH	CORROSION RESISTANCE	BRITTLENESS	REMARKS *
1	CARBON (C)	↑	↑	↓	↔	↑	↔	↔	DECREASE DUCTILITY
2	SILICON(Si)	↔	↔	↑	↔	↑	↑	↔	DEOXIDIZER "KILLING" STEELS
3	MANGANESE (Mn)	↔	↔	↑	↑	↔	↔	↔	REDUCE CRACK DURING WELDING
4	SULPHUR (S)	↔	↔	↓	↓	↔	↔	↑	BRITTLENESS
5	PHOSPHORUS (P)	↑	↔	↔	↔	↑	↔	↑	MACHINABILITY
6	MOLYBDENUM (Mo)	↑	↑	↔	↔	↑	↑	↔	HEAT RESISTANT
7	CHROMIUM (Cr)	↑	↑	↔	↔	↔	↑	↔	CORROSION RESISTANCE
8	NICKEL (Ni)	↑	↔	↑	↔	↑	↑	↔	CORROSION RESISTANCE
9	TITANIUM (Ti)	↔	↔	↔	↑	↔	↑	↔	WELDABILITY & CORROSION RESISTANT
↑ INCREASES				↓ DECREASES			↔ NEUTRAL		

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Table IV
Physical Properties For Steel

Material	Thermal expansion co-efficient (µm/m/°C)	Service temperature (°C)
Ferrite Materials		
SUS 441L	10.4	950
SUS 439 L	10.2	927
SUS 430	10.4	870
SUS 432 L	10.4	805
SUS 436 LM	9.3	806
Austenitic Materials		
SUS 304	16.9	925
SUS 309	14.9	980
SUS310	14.4	1150
SUS 316 Ti	16	925
Special Alloy		
Inconel 600	13.3	1095
Inconel 625	10.4	982
Inconel A286	16.4	700
FeCrAlloy	11.1	1300
Haste Alloy	6.4	-
Kanthal LT	11	1100
Alkrathol 3	11	1000

Table V
Mechanical Properties (Lab Test Result)

Mechanical properties for steel				
Material	**Yield Strength (N/mm²)**	**Tensile Strength (N/mm²)**	**Elongation (%)**	**Hardness (HV)**
SUS 441L	270	480	38	166
SUS 439L	260	415	36	165
SUS 304	345	605	55	164
SUS 432L	260	456	32	152
SUH 409L	263	427	35	134
SA1D	198.6	314	42.6	105
SS400	310.12	453.51	30.42	162
S10C	625.26	651	14.5	172
SUS 430J1L	323	472	31	169
SUS 436L	281	479	33	152
Inconel 600	285	590	40	150
Inconel 625	510	910	45	200
Inconel A286	298	632	42	-
FeCrAlloy	450	610	21	185
SUS310	212	532	43	-
Inconel 601	456	788	46	-
SUS316	296	589	52	-
Kanthal LT	555	762	18	218
Alkrathol 3	352	502	22	187

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Table VI
Chemical Properties (Lab Test Result)

Chemical Composition for Steel in %							
Material	**C**	**Mn**	**Si**	**Cr**	**Mo**	**Ni**	**Ti**
SUS 441L	0.02	0.56	0.63	17.59	0.01	0.27	0.28
SUS 439 L	0.02	0.25	0.65	17.13	-	0.28	0.36
SUS 304	0.04	1.59	0.34	19.73	0.11	9.18	0.01
SUS 436 LM	0.01	0.06	0.09	18.18	0.89	0.30	0.29
SA1D	0.01	0.15	-	-	0.02	-	0.05
FE 410	0.13	0.55	0.17	0.03	0.02	-	-
SPHC	0.05	0.19	0.03	0.02	0.02	-	0.02
STKM 12 A	0.13	0.14	0.04	0.01	0.03	0.17	-
STKM 11A	0.09	0.56	0.13	0.11	0.06	0.11	-
Inconel 600	0.10	0.75	0.30	15	-	68	-
Inconel 625	0.09	0.35	0.47	20.56	8.69	58.89	0.29
Inconel A286	0.05	1.2	0.89	14.23	1.25	24.68	1.95
FeCrAlloy	0.03	0.09	0.16	20.36	-	-	-
SUS310	0.04	1.36	0.06	24.56	-	19.23	-
Inconel 601	0.06	-	0.35	21.23	-	58.63	-
SUS316	0.06	1.26	0.24	15.6	2.2	10.8	-
Haste Alloys	0.01	0.57	0.16	16.23	14.8	-	Fe 2.7
Kanthal LT	-	-	-	18.21	-	-	Fe 66.8
Alkrathol 3	-	-	-	13.35	-	-	Fe 72.8

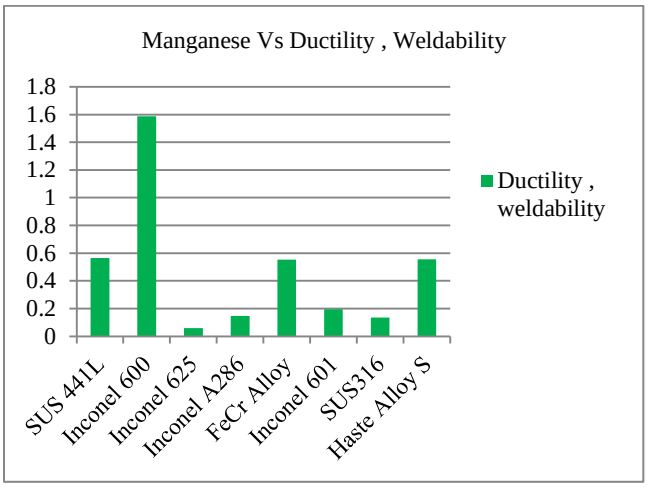

Fig 14 Manganese Vs Ductility, Weld ability

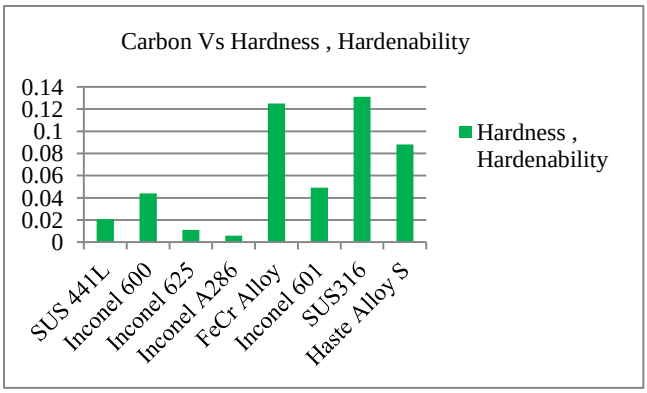

Fig 15 Carbon Vs Hardness, Hardenability

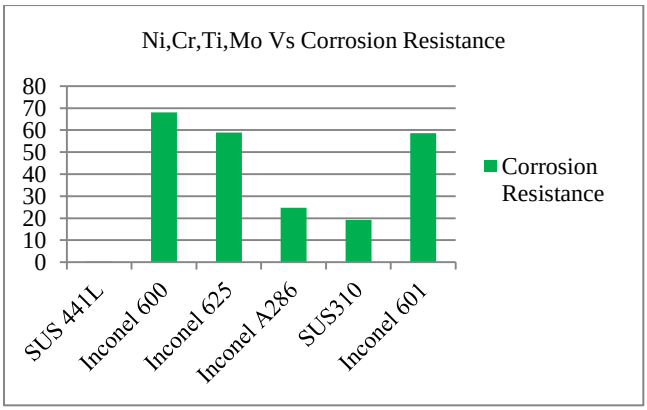

Fig 16 Ni,Cr,Ti,MoVs Corrosion Resistance

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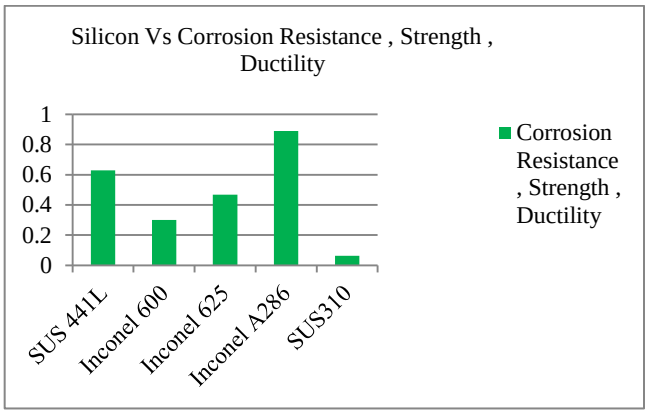

Fig 16 Silicon Vs Corrosion Resistance, Strength, Ductility

V. CONCLUSION

Materials for automotive exhaust system are discussed in detail. Materials used for conventional and special applications are described. The chemical, mechanical and physical properties of the materials required for the exhaust system are being considered in depth. The effect of additives to the base material is also explained.

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REFERENCES

[1] WWW.AZOM.COM
[2] WWW.STAL.COM/CN.
[3] JIS HAND BOOK FERROUS MATERIALS & METALLURGY I, II(2001 EDITION)
[4] [JIS G (3141:2009, 3131:2010, 4303:2005, 3101:2010, 4051:2009 , 3314:2010, 3445:2010,4305:2005,4312:1991)].
[5] IS 3589:2001.
[6] WWW.JFE-STEEL.CO.JP/../GLE-001.PDF.
[7] WWW.POSCO.COM/../STAINLESS.PDF.
[8] WWW.EFUNDA.COM/.
[9] Metals.about.com/od/metallurgy/a/The-Effect-of-Alloying-Agents-on-steel-properties.htm
[10] S. Rajadurai, L. Geer, C. Chung, H. Cheng, B. Snider, T. Carlson and J. Michels, H.Schwallbach, A. Montalbano, B.Chomicz, W. Ickes and R. Beason1999Shoebox Converter Design for Thin wall Ceramic Substrates
[11] Sivanandi Rajadurai, Shiju Jacob, Chad Serrell, Rob Morin and ZlatomirKircanski, 2006, Durable Catalytic Converter Mounting with Protective and Support Seals.

Abbreviations:

SUS	Steel use Stainless
SUH	Stainless Steel Heat Resistance
SS	Structural Steel
STZC	Steel Zinc Coated
FE	Ferrous
SPHC	Steel Plate Heat Commercial
SPCC	Steel Plate Cold Commercial