

Alternative technologies for stainless steel applications to I.C. engines exhaust manifolds

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Abstract

Both existing new and expected future legislation for I.C. engine exhaust gas emissions are leading to change the automotive components with a view to limit the greenhouse effect and the atmospheric pollution. Major effort will lead to a weight reduction of cars in order to reduce fuel consumption. A high efficiency catalytic exhaust system will be a must in the next few years.

Exhaust manifolds in stainless steel are considered an interesting solution able to satisfy both weight saving and emission constraints. Innovative technologies that substitute the traditional cast iron solutions are:

- Hydroforming making manifolds by welding thin walled stainless steel tubes that have been shaped by hydraulic pressure
- Precision vacuum casting making manifolds as a single near net shape thin wall casting.

The employ of these technologies makes it possible to reduce the weight of a manifold by up to 40% and, thanks to the use of stainless steel, still support high optimal exhaust gas temperatures above 800 °C giving best catalytic converter performance results.

In addition less machining operations are required on both products if compared to traditional cast iron for a cost competitive part.

Riassunto

Le normative che regolamenteranno le emissioni/consumi dei veicoli di prossima generazione stabiliscono limiti ottenibili anche attraverso una evoluzione dei sistemi di scarico. Risulteranno necessari sistemi catalizzati ad elevata efficienza.

I collettori di scarico in acciaio inossidabile risultano di particolare interesse viste le loro caratteristiche ad elevata temperatura.

Le soluzioni tradizionali in ghisa potranno venire sostituite da versioni in acciaio inossidabile adottando tecnologie innovative di trasformazione quali l'idroformatura di tubi o la fusione in parete sottile sottovuoto.

L'impiego di tali tecnologie permette inoltre una riduzione di peso del componente fino al 40%.

Risultati positivi sono già stati ottenuti con acciai inossidabili ferritici ed austenitici. Sono in fase di sviluppo soluzioni in cui l'impiego di acciai duplex innovativi, di recente introduzione nell'industria automotive, può garantire interessanti prestazioni del prodotto finale.

KEYWORDS

Exhaust manifold, hydroforming, precision vacuum casting.

INTRODUCTION

The basic design and materials for exhaust manifolds have remained relatively unchanged until the eighties. Gray iron and nodular iron were satisfying requirements at operating conditions (i.e. gas temperature around 700°C) providing a good compromise between performances and costs [1].

During the 80's the development of catalyzed engines with improved performances lead to an increase of operating temperatures up to 900°C. In addition to the thermal fatigue life target the scaling resistance has become a must to avoid catalyst damaging. High Si-Mo nodular iron and Ni resist ductile iron were introduced to solve the problem. For higher temperatures the only reliable material solution is stainless steels (Figure 1).

Stainless is today used on many luxury cars engine because of the high cost (material and transformation).

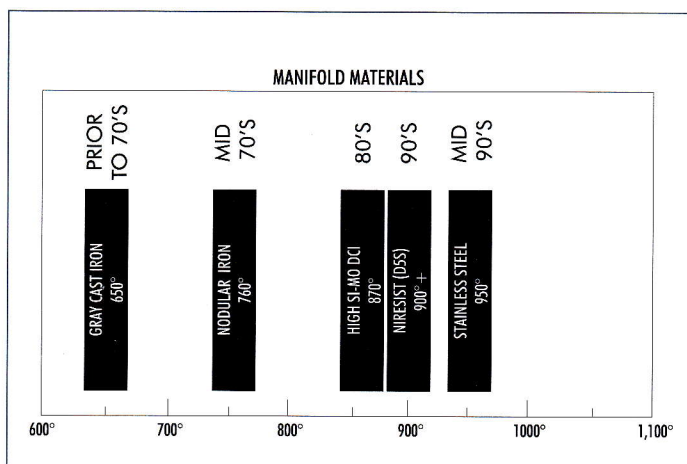


Fig. 1: Evolution of exhaust manifold materials

New regulation for emissions, low fuel consumption and car's component weight reduction is affecting the operating conditions and performances targets of the exhaust manifold for the year 2000. Not only luxury cars will be affected: a high demand for low cost stainless steel manifold will rise.

The demand for lower fuel consumption can be achieved with engines working close to the stoichiometric air/fuel ratio. This working condition leads to higher exhaust gas temperatures likely reaching the 950°- 1000°C as outlined in Figure 2.

Current materials will not provide adequate life at those temperatures also because of the trend in giving to the customer an extension of vehicle warranty period or mileage. Stainless is likely to be the only alternative to satisfy these new trends. Two interesting technologies to shape stainless into the complex geometry required by the design of exhaust manifolds are:

- Hydroforming
- LSVAC (Loose Sand Vacuum Assisted Casting) [2]

Based on the industrial experiences done so far, both of them could provide low cost solutions for high volume production. These technologies can be applied only to those steels that have precise features, for example the first technology needs a material with high plastic deformation and weldability, while

HYDROFORMING OF STAINLESS STEELS

The hydroforming process is increasingly widely used to produce complex closed section components for the automotive. Mild steel, deep drawing steel and aluminum have been successfully transformed into shaped components since the 1983 [4].

Technology development has made feasible also the shaping of stainless steel tubes. In industrial applications pre-bent, deburred ends tubular blanks are commonly used. These blanks are placed into a split die, the halves of which close to deform. Subsequently plungers are axially introduced to the tube ends sealing these against the hydraulic medium (water) to be injected. The medium is supplied and pressure applied by a separate high-pressure unit through bores in the plunger. The tube is forced into the internal contour of the die cavity. Pressure is then relieved when the blank is formed into the desired shape. Additional compression and expansion pressure can be applied in combination with internal water pressure to optimize deformation. (Figure 3) [5].

The control of the internal pressure, as well as the axial flow or compression of the material, in combination with volume control and speed changing are of great importance for a successful forming.

Playing with tool design using inserts a flexibility can be achieved at competitive costs in the development stage, helping the achievement of short time to market (Figure 4).

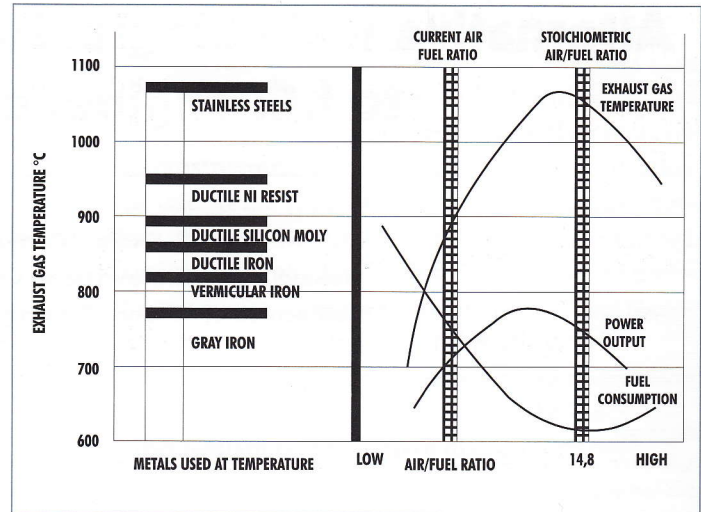


Fig. 2: Comparison of alloys to engine operations at different air/fuel ratios

for the second one good castability is required. Moreover these steels have not to change their structural properties during the maintenance at the working temperature (700-950 C) and their properties concerned with creep, environmental corrosion and thermal shock have to good. [3]

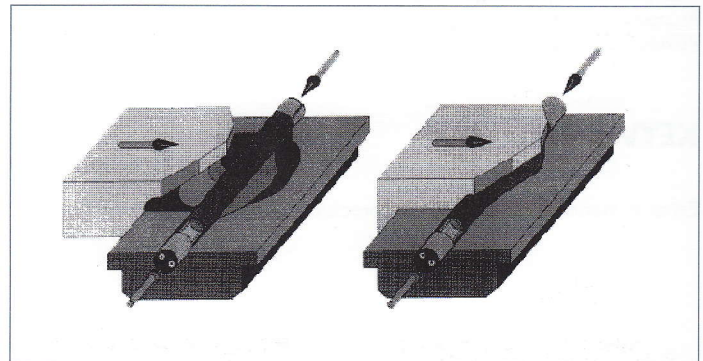


Fig. 3: Typical hydroforming process steps

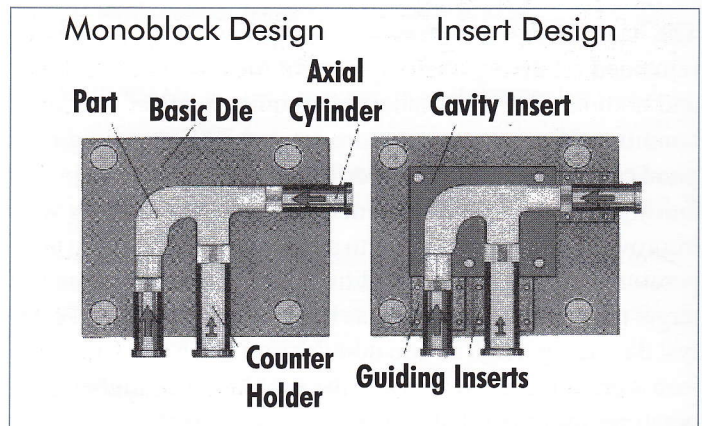


Fig. 4: Tool insert design for flexibility in the development stage

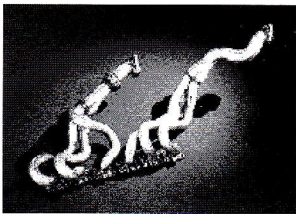
Today, longitudinally welded tubes constitute the most cost-effective alternative for blanks. The weld seam has to be put in the less deformed area. Complex geometry has to be stress-free annealed after forming. The following table gives an overview of the stainless steels that can be hydroformed into

exhaust manifolds. In table 1 some stainless steel are showed than can be hydroformed into exhaust manifolds. In Figure 5 some examples of exhaust manifold today into production are presented [6].

TABLE 1 - Stainless steel for hydroforming

Material	Rp (N/mm2)	Rm (N/mm2)	A 80%	Notes
1.4016	> 270	450-600	> 18	Hard to shape
1.4512 X6CrTi12	>220	390-560	>20	Applied in cooler area Difficult to shape
1.4509 X6CrTiNb12	>290	420-600	>20	High heat resistance suitable for hot areas
1.4541 X6CrNiTi1810	>230	540-740	>40	
1.4401 X5CrNiMo17122	>240	550-700	>40	
1.4401 X15CrNiSi2012	>230	500-750	>22	
1.4301 X5CrNi1810	>220	550-750	>40	Easy to shape

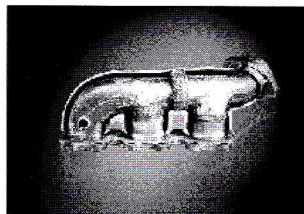
Example of Application: Exhaust Systems



Exhaust manifold BMW M3

Input pipe: Ø 32 x 2 mm
Ø 48,3 x 2 mm

Material: 1.4301
Series
manufacturer: Schmitz + Brill
GmbH



**Exhaust manifold Mercedes
6 cylinder**

Input pipe: Ø 42 x 1,25 mm
Ø 48,3 x 2 mm

Material: 1.4825 1.4893
Series
manufacturer: Leistritz GmbH

Fig. 5: Example of exhaust hydroformed manifold in production

LSVAC (Loose Sand Vacuum Assisted Casting)

Oxidation and corrosion resistant alloys have been difficult to cast into thin sections using the traditional gravity casting methods due to the high melting point and low fluidity of these alloys.

The vacuum assisted processes have been recently improved (5) to satisfy high demanding design like exhaust manifold. In particular LSVAC not only makes thinner (2.5 mm) and larger castings possible, but also results in significantly lower production costs and less core sand use.

In the LSVAC process (Figure 6) a preformed aluminum foil covers a contoured mold base. Molds and a casting flask are placed on the foil and dry unbonded sand is used to fill the rest of the flask. The molds are very thin walled, usually from 3 mm to 12 mm. The dry sand supports the mold so wells that the mold needs only to be thick enough to handle.

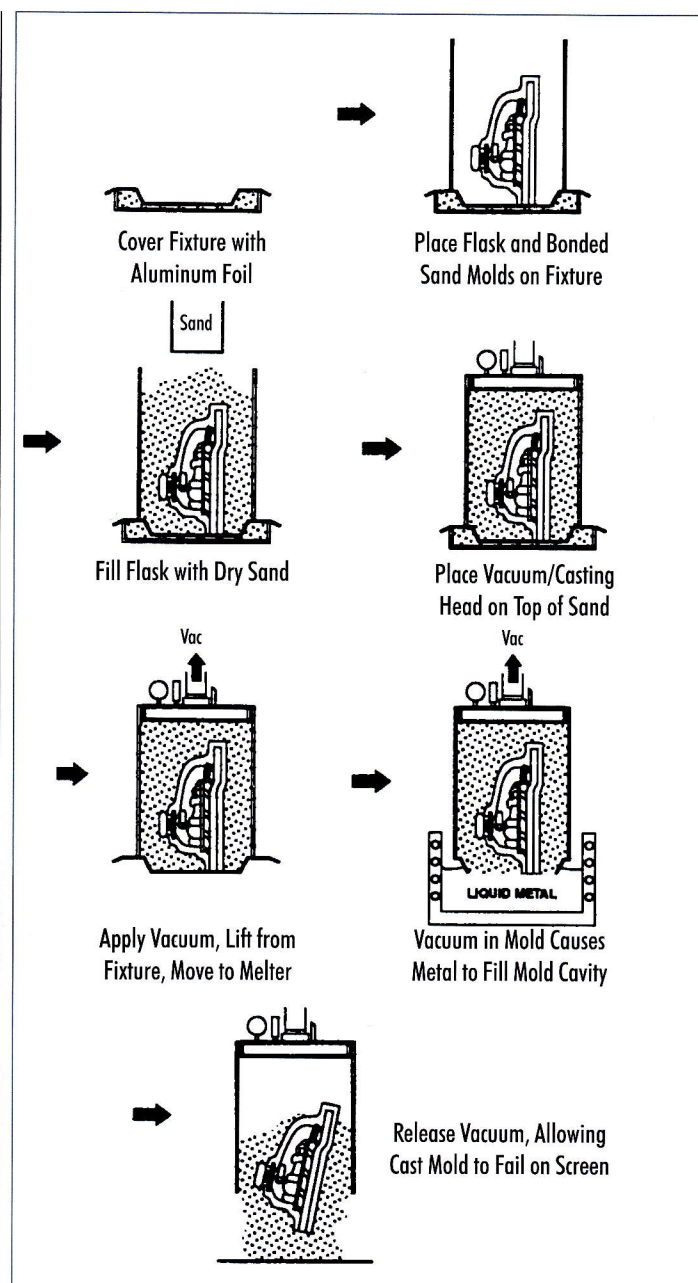


Fig. 6: LSVAC process applied to exhaust manifold

A vacuum head is placed in the flask and vacuum is applied. The vacuum rigidifies the sand and holds the foil tightly against the sand and the mold. The flask is then moved to a furnace of steel and dipped into its surface. The foil melts immediately and the metal fills the mold very rapidly. The fast filling time combined with vacuum control guaranty a good quality of the thin walls.

A ferritic stainless steel has been developed for exhaust manifolds with a low coefficient of thermal expansion if compared to austenitic and high Si-Mo irons.

The nominal composition of this alloy is 12.5% Cr, 1.8% Si, 0.03% C stabilized with Ti and Nb.

An intensive activity of research is under way in order to evaluate other stainless steel with improved thermal fatigue properties.

Automated production equipment for LSVAC process became operational in early 1996. In figure 7 various types of thin wall stainless steel manifolds are showed.

TECHNICAL AND ECONOMICAL COMPARISON

As outlined both technologies represent interesting alternatives to produce exhaust manifolds for the engines of the years 2000. In the following table 2 an attempt of technical and economical comparison has been described.

TABLE 2 - Technical and economical comparison

Topic	Hydroforming	LSVAC
Minimum wall thickness (mm)	1.0 - 1.5	1.5- 2.0
Variable section	Yes	Yes
Variable thickness	No	Yes
Roughness	+++	+
Part integration	+	+++
Weight reduction	+++	++
Component life		
Oxidation resistance	+++	+++
Thermal fatigue	++	+++
Visual appearance	+++	+
Cost		
Production cost	00	00
Piece cost	0	0
Tooling	00	0
+++ very good ++ good + bad	00 high 0 low	

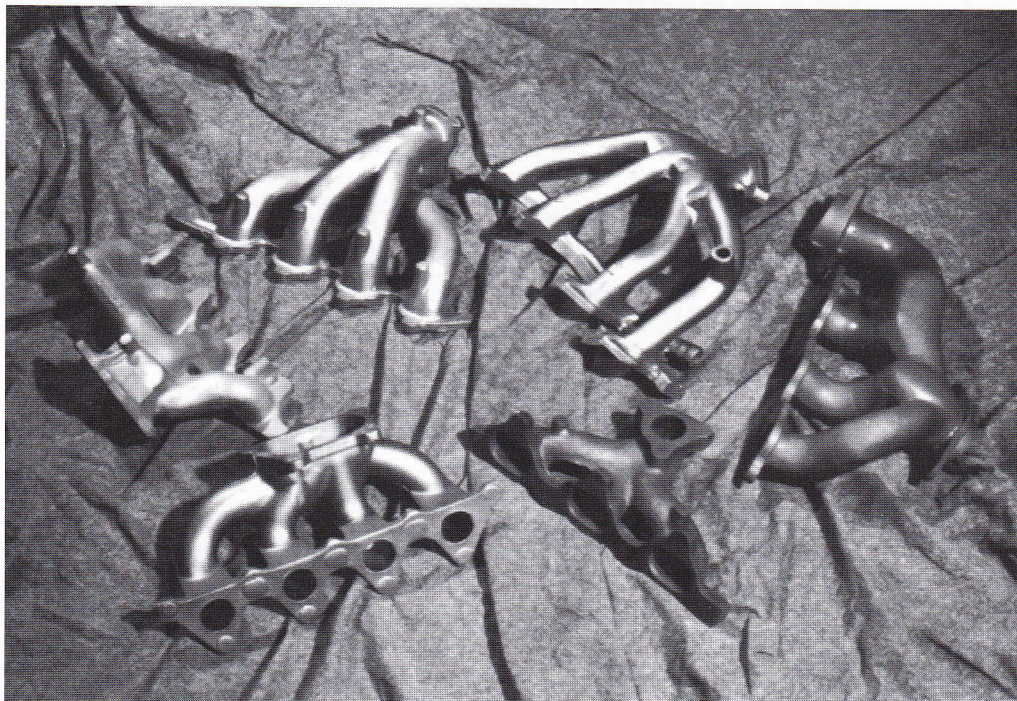


Fig. 7: Thin walled exhaust manifolds made by the LSVAC process

CONCLUSIONS

Stainless steels represent today the only alternative materials for the future hotter parts of the exhaust system (exhaust manifolds). To penetrate the automotive market for high volume production a cost reduction of the components has to be achieved.

New technologies are available to shape stainless steels into complex geometry required by the engine designers at interesting cost.

Further developments are required to optimize customized steels for both transformation technologies here described (hydroforming and LSVAC). The only aim of this work is to show the two alternative technologies to produce the exhaust manifolds. Certainly, the new developments of these technologies will depend on several kinds of stainless steels that can satisfy the technological needs and the operative conditions[8]. The best possibilities of success seem to belong to the last generation of ferritic stainless steel, but there is also the possibility to design new and suitable duplex stainless steels that are already present in the field of automotive manufacturers [9].

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REFERENCES

- [1] G.D. CHANDLEY, J. REDEMSKE, J. JOHNSON, R. SHAW, P. MIKKOLA, *Exhaust manifolds in stainless steel*, SAE Paper 970920, 1997.
- [2] G.D. CHANDLEY: *The LSVAC process*, SFSA, 1997.
- [3] T. Sunami et al., *Global market development forum for stainless steels*, Toronto, Canada, 1992, June, p. 45.
- [4] HYDROFORMING CONGRESS, Nov. 1997, Bochum (D).
- [5] D. SCHMOECKEL, *The hydroforming of stainless steel*, IPT Darmstadt Internal Document, 1998.
- [6] SCHAFER Hydroforming- Shuler Group (D). Internal document, 1998.
- [7] HITCHINER MANUFACTURING CO. - USA.
- [8] M. Barteri et al., *Low weldable ferritic stainless steel for hot and automotive exhaust gas system*, 3rd European Congress Stainless Steel '99, Chia Laguna, 6-9 June, vol.1 p.75.
- [9] J.M. et al., *High ductility low nickel duplex for higher transport vehicles*, 3rd European Congress Stainless Steel '99, Chia Laguna, 6-9 June, vol.1 p.85.