Stainless steel metal cored wires for welding automotive exhaust systems

by Stanley E. Ferree and Michael S. Sierdzinski, ESAB Welding and Cutting Products, Hanover (PA), USA

Over the past two decades, advances in stainless steel materials and the designs of automotive exhaust systems have led to longer life cycles and extended warranties. This paper will describe the development of stainless steel metal-cored (SSMC) wires and their expanded use for welding these improved automotive exhaust systems. Information on manufacturing methods, core ingredients, available alloy types and application data will be presented.

Background

In the past, automotive exhaust systems were expected to last for only three to four years. A major change occurred in the United States in 1970 with the Clean Air Act, which forced car makers to add catalytic converters to exhaust systems. In the mid-1970s, environmental mandates for catalytic converters with five-year/50,000-mile warranties forced car makers to abandon carbon steel systems in favour of 409 ferritic stainless steel (1). In addition, austenitic stainless steels and hot-dipped aluminium-coated ferritic stainless steels were used for some demanding applications. Because of competitive pressure and consumer demands, today's exhaust systems usually have life cycles and warranties of seven to ten years. Table 1 shows the major stainless steel alloy types that are now used to make automotive exhaust systems (2).

Although ferritic stainless steels have been used for certain automotive exhaust components since 1961 (3), their expanded use to include complete exhaust systems has only occurred over the past 10 years. Today's automotive exhaust systems can be divided into two parts: a hot and a cold end (4). The hot end includes the exhaust manifold, downpipe, flexible coupling and catalytic converter. The cold end includes the resonator, intermediate pipe, silencer and tail pipe. Important material properties and considerations for the hot end of the exhaust system include high-

Alloy	C	Mn	Si	Cr	Ni	Ti	Nb	Mo	Al
Aluminised steel type 1, Al409 and Al439				Carbon and stainless steels/aluminium- coated					
409	0.010	0.25	0.50	11.20	0.25	0.20	—	—	—
439	0.015	0.25	0.30	17.30	0.25	0.30	—	—	—
11 Cr-Cb	0.010	0.25	1.30	11.30	0.25	0.20	0.35	—	—
18 Cr-Cb	0.015	0.25	0.40	18.00	0.25	0.25	0.55	—	—
12 SR	0.015	0.25	0.60	12.00	—	0.25	0.50	—	1.2
18 SR	0.015	0.25	0.60	17.30	0.25	0.25	—	—	1.7
304L	0.025	1.75	0.30	18.10	8.50	—	—	0.20	—
321	0.040	1.30	0.60	17.25	9.75	0.40	—	—	—
409 Ni	0.010	0.75	0.35	11.00	0.85	0.20	—	—	—

Table 1. Typical alloy composition (wt%) of materials for exhaust systems (2).

temperature oxidation resistance, fatigue strength and the coefficient of thermal expansion. The important points when it comes to the cold end of the exhaust system are condensate corrosion and aqueous salt corrosion.

The ferritic 11% Cr alloys are popular choices for many exhaust components and systems. However, to comply with the long-term durability requirements, such as a 10-year/100,000-mile warranty, the higher chromium (17–20% Cr) ferritic stainless steel grades are often used.

A number of joining processes are used to fabricate these advanced automotive exhaust systems. They include high-frequency resistance welding, laser welding, resistant spot welding, gas tungsten arc welding, brazing and gas metal arc welding (GMAW) with solid or metal-cored wires. Welding stations may also be designed for semi-automatic, mechanised, or fully robotic welding applications. The process chosen by exhaust system fabricators depends on various factors. The complexity of the parts, the number of varieties and quantities produced, the required capital expenditure and production cost-profit analyses all play an important role in determining the process. However, the GMAW process using solid or metal-cored stainless wires has evolved as one of the favourites for welding the new automotive exhaust systems. In addition, it soon became apparent to exhaust system fabricators using the GMAW process that it was much easier and less costly to obtain customised stainless steel metal-cored wires than solid wires for welding the modified or new stainless steels which are used in these systems. Along with the availability of a wider range of alloy modifications, the SSMC wires also offered welding fabricators advantages in terms of improved quality, increased productivity and reduced costs.

Figure 1. Automotive exhaust components welded with 1.2 mm Arcaloy 18CrCb showing joint complexity and

a) Cut-away view of flexible exhaust decoupler showing complexity of joint and variety of thicknesses. Weld joints are near the top on the outside, joining four parts, and on the bottom inside, sealing two parts to the flange

b) Flexible exhaust decoupler showing weld joining decoupler to tube

c) Bottom view of b) showing the inside of the flange weld

d) Example of flexible exhaust connector

Design of stainless steel metal-cored wires

Some of the advantages of SSMC wires are a result of their tubular design. SSMC wires are made by forming a steel sheath into a U-shape, filling it with ferroalloys and other core ingredients, closing the sheath into a tubular shape and then drawing or rolling the formed tube down to the required size. A low carbon mild steel sheath is commonly used to make ferritic stainless steel alloys, while a 304L grade of sheath is usually used for making the austenitic alloys (5).

The tubular structure of SSMC wires offers several advantages compared with solid wires. As previously mentioned, many alloy types are easily made by changing the ferroalloys in the core ingredients. Some automotive exhaust system manufacturers want 409 types stabilised with Ti or Nb and/or with Ni additions, while others prefer modified 17–18% Cr alloys with similar al-

Wire	ESAB Arcaloy 18CrCb	Solid 439Ti
Size	1.2 mm (0.045 in.)	0.9 mm (0.035 in.)
Current (A)	245	245
Voltage (V)	23	23
Wire feed speed	8.6 m/min (340 ipm)	8.6 m/min (340 ipm)
Travel speed	1.5 m/min (60 ipm)	0.7 m/min (26 ipm)
Deposition rate	18.9 kg/h (8.6 lbs./h)	11.7 kg/h (5.3 lbs./h)
Arc time per weld	12 seconds	30 seconds
Shielding gas	95 Ar/5 CO_2	95 Ar/5 CO_2

Table 2. Application data for Arcaloy 18CrCb SSMC wire and a solid 439Ti wire.

loy additions. Customised austenitic alloys are also easy to make using a tubular designed metal-cored wire.

Potassium, sodium or lithium arc stabilisers are often added to the core ingredients to reduce welding spatter and/or to produce good arc stability at the low welding currents required for thin-gauge applications. Small amounts of fluoride compounds and/or oxide compounds also may be added to improve weld metal wetting. In general, a spray transfer with lower spatter levels and a wider bead flow can be achieved at lower current settings than is possible with solid wires. SSMC wires are therefore less prone to burn-through problems on thin-gauge sheet metal and are more tolerant of joint gap variations. In overall terms, a higher level of quality, with fewer defects and lower part rejection rates are often achieved with SSMC wires.

Application information

In many applications, faster welding travel speeds are attainable with SSMC wires than with solid wires because of the tubular design of SSMC wires. Their inherent higher current density characteristics produce faster wire melt-off rates than solid wires. Some exhaust system fabricators have doubled their welding travel speeds when changing to SSMC wires because of their faster melt-off rate. Table 2 shows the improved productivity results for an SSMC 18CrCb wire compared with a solid 439Ti wire, when welding flange joints on decouplers. The arc time per weld was reduced from 30 seconds with the solid wire to 12 seconds with the metal-cored wire. Less penetration and better bead profiles were also found with the SSMC wire.

Some of the components in the newer exhaust systems also have complex joints containing a variety of stainless steel alloys and sheet thicknesses (Figure 1). The SSMC wires appear to be more tolerant than solid wires of the complexities involved in welding these joints. The special additions made to their core ingredients and their tubular design produce this advantage.

The optimum wire diameter for welding most joints on exhaust systems is 0.9 mm (0.035 in.) for solid wire and 1.2 mm (0.045 in.) for SSMC wires. However, on some very thin-gauge parts (< 1 mm), 1.0 mm (0.040 in.), SSMC wires may be used to prevent burn-through problems. For the same reason, the pulsed-arc transfer mode is more commonly used than a spray transfer, except on thicker tube-to-flange joints.

The shielding gas for solid and SSMC wires is usually a mixture of argon and oxygen or carbon dioxide (95-98% Ar/Rem. O_2 or CO_2). Sometimes, tri-mixes that include hydrogen or helium are used in these applications. The shielding gas is selected to optimise the welding operability or performance characteristics. However, the proper Ti:C or Nb:C ratios must be maintained in the weld deposit to tie up the free carbon and nitrogen and reduce the formation of Cr carbides. Sensitisation or the formation of Cr carbides reduces wet corrosion resistance and leads to intergranular attack (1).

Any change in gas composition requires a weld metal analysis to ensure acceptability. Table 3 shows the typical effects of the most common shielding gases on the weld metal composition of an SSMC 18CrCb wire. As expected, the carbon content increases slightly when using a shielding gas containing CO2. The shielding gas composition has little effect on the other elements. A similar trend is found with solid wires (6, 7).

ESAB's stainless steel metal-cored wires

Ferritic grades

Five ferritic SSMC wires are being produced for the automotive exhaust system industry: Arcaloy 409Ti, 409Cb, 436, 439 and 18CrCb. The choice of filler metal depends on cost, availability and performance, such as superior corrosion, oxidation and creep resistance. A description of each product now follows and Table 4 shows the typical weld metal analysis.

Arcaloy 409Ti (AWS A5.9-93, EC409) Arcaloy 409Ti is a 10.5–13.5% Cr alloy stabilised with Ti for arc

	C	Mn	Si	P	S	Cr	Ti	Nb
98 Ar/2 O_2	0.017	0.53	0.48	0.011	0.013	18.6	0.34	0.40
95 Ar/5 O_2	0.016	0.49	0.43	0.011	0.013	18.0	0.27	0.40
95 Ar/5 CO_2	0.032	0.54	0.47	0.011	0.013	18.2	0.35	0.43

Welding conditions 235 A, 24 V, DCEP, 7.9 m/min wire feed speed, 12.5 mm contact tip to work distance.

Table 3. Effects of shielding gas composition on the weld metal composition of 1.2 mm Arcaloy 18CrCb SSMC wire.

	C	Mn	Si	P	S	Cr	Ti	Nb	Mo
Arcaloy 409Ti	0.020	0.48	0.55	0.010	0.008	11.6	0.90	—	—
Arcaloy 409Cb	0.015	0.45	0.55	0.011	0.010	11.7	—	0.60	—
Arcaloy 436	0.020	0.60	0.50	0.010	0.009	17.3	0.60	—	1.20
Arcaloy 439	0.020	0.50	0.45	0.010	0.010	18.0	0.60	—	—
Arcaloy 18CrCb	0.018	0.50	0.45	0.011	0.011	18.5	0.25	0.50	—

Table 4. Typical undiluted weld metal analysis (%) with 98 Ar/2 O_2 shielding gas for ferritic SSMC wires.

	C	Mn	Si	P	S	Cr	Ni	Mo
Arcaloy MC308L	0.027	1.50	0.50	0.015	0.006	20.1	10.3	0.1
Arcaloy MC309L	0.014	1.53	0.51	0.016	0.006	24.1	12.6	—
Arcaloy MC316L	0.026	1.43	0.55	0.024	0.006	18.8	12.5	2.5

Table 5. Typical undiluted weld metal analysis (%) with 100% Ar shielding gas for austenitic SSMC wires.

stability and to form carbides to improve corrosion resistance, increase strength at high temperatures and promote the ferritic microstructure.

Arcaloy 409Cb (AWS A5.9-93, EC409Cb) Arcaloy 409Cb is the same as Arcaloy 409Ti, except that Cb(Nb) is used instead of Ti to achieve similar results.

Arcaloy 436 (no AWS classification) Arcaloy 436 is a 16.5–18% Cr alloy stabilised with Ti and with a 1–1.5% Mo addition for improved resistance to condensate corrosion and aqueous salt corrosion.

Arcaloy 439 (no AWS classification) Arcaloy 439 is a 17–19% Cr alloy stabilised with Ti. The higher chromium content provides an increased level of oxidation and corrosion resistance compared with the 409 grades.

Arcaloy 18CrCb (no AWS classification) Arcaloy 18CrCb is a 17.5–19.5% Cr alloy similar to Arcaloy 439 but stabilised with both Ti and Cb(Nb). The dual stabilisation helps to prevent carbide sensitisation during welding and high-temperature exposure.

Austenitic grades

Three austenitic grades are also available for these applications: Arcaloy MC 308L, MC309L and MC316L. A description of each product now follows and Table 5 shows the typical weld metal analysis.

Arcaloy MC308L (AWS A5.9-93, EC 308L) Arcaloy 308L can be used to weld AISI types 301, 302, 304, 304L, 308 and 308L.

Arcaloy MC309L (AWS A5.9-93, EC 309L) Arcaloy 309L is designed for welding dissimilar joints between carbon steels and various stainless steels.

Arcaloy MC316L (AWS A5.9-93, EC 316L) Arcaloy 316L is used to weld AISI 316 and 316L grades of stainless steel when pitting corrosion is a problem.

Packaging

The Arcaloy family of ferritic and austenitic SSMC wires is sold to major car manufacturers and their suppliers of exhaust components or assemblies. They are packaged in 15-kg (33 lb.) and 20-kg (44 lb.) spools and 227-kg (500 lb.) Marathon Pacs. The Marathon Pac has become the preferred package for many exhaust system fabricators. Down time is reduced as fewer changeovers are needed with this larger package size.

Summary

Advances in the design of automotive exhaust systems have led to a new family of stainless steel metal-cored wires that are rapidly becoming the favourite choice of welding fabricators in this industry. They offer the following advantages compared with solid wires:

1. Customised chemistry requirements are readily available
2. Increased travel speeds and deposition rates help reduce costs
3. More tolerant to poor fit-up with better wetting characteristics
4. Higher level of quality — fewer weld defects
5. Overall welding costs are usually lower

References

1. The Catalyst, Beyond 409, ARMCO Inc., Issue No. 3, 1998.
2. Automotive Exhaust Systems Materials Comparator, ARMCO Inc., 1995.
3. Heat Resisting Ferritic Stainless Steels for Automotive Exhaust System Components, Allegheny Ludlum Steel Corporation.
4. Dowthett, Joseph A. 1997. Designing Stainless Exhaust Systems, ARMCO, Inc. Technology Center.
5. Ferree, S. E. 1992. Status Report on Small Diameter Cored Stainless Steel Wires. Welding Journal. 71 (1): 47 to 55.
6. Stenbacka, N. and Persson, K.A; Shielding Gases for Gas Metal Arc Welding. Welding Journal. November 1989, 41 to 47.
7. Geipl, H. and Pomaska, H., MAGM Welding Stainless Steel—Effect of Shielding Gas. Sonderdruck #101. Linde AG, Hoellriegelskreuth, Germany.

About the authors

Stan Ferree is vice president, technical for ESAB Welding and Cutting Products, Hanover, PA, USA. He is responsible for the research and development of welding consumables and their applications.

Mike Sierdzinski is a research scientist for ESAB Welding and Cutting Products, Hanover, PA, USA. He has worked in a number of welding consumable development areas, from manual electrodes to cored wires. He is currently involved in the development of very low hydrogen flux-cored wire and stainless steel metal-cored wire.