High-productivity arc welding is ideal for fabrication of vehicle frames and subassemblies, including suspensions, engine cradles, and similar parts. The gas-metal arc welding (GMAW) process is already widespread in the automotive supplier network for steel, and is increasing for aluminum. Currently, the resistance spot welding (RSW) process is the typical choice for vehicle BIW manufacturing from sheet metal stampings. However, interest in the possibilities offered by tubular spaceframe vehicle structures in both steel and aluminum alloys has spurred renewed interest in GMAW for spaceframe manufacturing. A significant example is the aluminum Audi A8, made from a GMA-welded tubular spaceframe comprised largely of aluminum extrusions and cast aluminum nodes.

The arc welding industry has been busy producing an array of GMAW equipment with ever-increasing reliability and stability. This article describes pulsed, variable polarity, and twin-wire GMAW, as well as plasma arc welding of automotive structures.

Pulsed GMAW

The pulsed GMAW (P-GMAW) process has been widely reviewed before, and the benefits are considered to be well understood in the automotive supplier network, especially among the Tier 1 suppliers. Current pulsing has the benefit that spray transfer can be achieved across the entire range of wire feed speed. Electronically linking the pulse parameters to the wire feed speed maintains the most stable arc conditions, and these relate directly to weld quality, consistency, and very low spatter levels. Electronic pulsing also allows spray transfer to be suitable for out-of-position welding, which is likely to be very useful in the fabrication of steel and aluminum spaceframes.

Attached to a modern six-axis welding robot or other mechanized welding system, this provides a very flexible manufacturing tool. P-GMAW has been preferred since the late 1980s by automotive suppliers such as A.O. Smith (now Tower Automotive), which had several hundred machines in production welding operations at that time (and today) for welding light truck frames and other parts. Until recently, almost all applications were for steel. Over the past several years, P-GMAW of aluminum alloys has become more accepted, especially for components such as suspension parts and engine cradles. For example, the Audi A8 spaceframe (Fig. 1) is welded predominantly with P-GMAW.

Variable polarity GMAW

Traditional constant voltage (CV) GMAW always operated in direct current-electrode positive (DCEP) polarity, as does P-GMAW. On the other hand, variable polarity GMAW (VP-GMAW, also known as AC-GMAW), operates in a variable DCEP/DCEN (direct current-electrode negative) mode. Although AC gas tungsten arc welding (GTAW) has been available for many years, recent advances and cost reduction of power electronic devices have allowed development of commercially viable VP-GMAW equipment.

The main advantage of VP-GMAW over conventional GMAW, is that the ability to vary the balance of DCEN and DCEP polarity allows a significant improvement in the ability to control the degree of weld penetration. This enhances the ability to weld sheet
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metal components, particularly with regard to gap tolerance (Fig. 3). VP-GMAW is suitable for welding steel and aluminum sheet and tube material. Work at EWI has demonstrated the capability of the process to weld lap fillet joints with a gap of up to twice the thickness. While this is extreme, it demonstrates the potential for high robustness in a high-volume manufacturing environment.

**Twin-wire GMAW**

In twin-wire GMAW, two wires are fed to the same torch, Fig. 2. This has obvious implications for increased deposition rate and productivity in automotive component fabrication. The main advantage is the very high welding speeds, up to three to four times faster than single-wire GMAW for suitable applications on thicker material, above 3 mm (1/8 in.). The welding power and deposition rates are suitable for production of suspension parts, engine cradles, light truck, and SUV frames, but not for sheet metal parts or tubular spaceframe components made of thinner tube material.

Typical welding speeds for robotic twin-wire GMAW are in the range of 1.2 m/min (47 in./min) for a horizontal 6-mm leg length fillet weld, to 3 m/min (120 in./min) for a 3-mm lap fillet weld, and 6 m/min (240 in./min) for a cylinder having a 2-mm wall. These speeds are two to three times faster than conventional single-wire GMAW. Distortion can be reduced despite the higher welding power and deposition rate, because of the faster travel speeds in thin sections. This makes twin wire GMAW a very powerful tool for automotive fabrication: A trailer manufacturer recently purchased 30 such systems.

**Plasma arc welding**

PAW has long been a process with small-niche applications, despite the tremendous potential for increased penetration and productivity offered by the keyhole mode of operation. In the automotive area, plasma spot welding and melt-mode plasma welding with or without filler wire are receiving increased attention.

- **Plasma spot welding**: Plasma spot welding allows the arc spot-welding of multiple material stackups, if required, up to a limit of 8-mm thickness without prior preparation of pilot holes, and with single-side access requirements. Uncoated and coated steels, aluminum alloys, and stainless steels can be welded. PAW has the advantage over RSW in regard to single-side access, and presents new design flexibility. PAW produces higher tensile and fatigue properties than RSW. The compact torch design reduces the payload for robotic welding, improving the dynamic performance of the robot, Fig. 4.

PAW has the advantage over GMAW in that no pilot holes are required for the larger stack-ups or material thicknesses, because of the ability to penetrate up to 8 mm without material preparation. PAW spot welds can be made without filler wire, which avoids problems of spatter at the weld start associated with GMAW.

- **Melt-mode PAW**: Melt-mode plasma welding, with or without cold wire feed (Fig. 4), has an advantage over GMAW in that the weld fusion characteristics are such that almost the entire weld length can be "counted" as a structure. With GMAW, some of the weld length has to be discounted because of the start and stop characteristics of a GMA weldment, typically 8 mm (about 3/8 in.) at either end of the weld. This yields the advantage that shorter welds can be made with PAW, with higher potential productivity. The other advantage is that melt-mode welds have an improved cosmetic appearance suitable for more visible joints.

Aluminum alloy 6104 sheet for door panels has been successfully welded autogenously (without filler) with no cracking or porosity. Typical welding speeds for a lap-fillet joint are 1 to 2 m/min (40 to 80 in./min). Another advantage of PAW of aluminum is that, with an AC power source and VP switching, parts can be welded with much reduced cleaning time.

**Keyhole PAW**, which can penetrate up to 8 mm in a square-edge closed butt joint configuration, offers some potential for fabricating truck frames. However, the equipment cost and lack of sufficient suitable joint configurations (most joints are T-butt and fillet welded by GMAW or FCAW) largely preclude significant application.

**Spaceframe vehicle structures**

The primary driver for hydroformed tubular products in an automotive spaceframe is to increase stiffness while reducing body weight to enhance overall fuel economy and handling. This is obviously a major focus of the automobile manufacturers and involves a huge automotive supplier network to varying degrees, depending on their product mix. Very large automotive suppliers such as Magna and Tower Automotive are highly involved with hydroformed tubular products, and have already begun supplying such parts to the automotive industry, albeit in relatively small quantities, and for a limited number of vehicles at this time.

However, the growth potential is huge. Fabricating spaceframes with GMAW offers increased tolerances to joint gaps that develop in the assembly of the 3-D spaceframe, particularly near the end of the assembly and welding sequence. Laser welding of spaceframes is also a consideration, but the fit-up tolerances and lack of tolerance to joint gaps make it somewhat less than a practical proposition at this time. The robustness to joint gaps offered by GMAW is particularly attractive in this respect.