Effects of SO_2 Shielding Gas Additions on GTA Weld Shape

Small additions of SO_2 in argon shielding gas for GTA welding both suppresses variability and improves joint penetration in 21-6-9 and 304 stainless steels

BY C. R. HEIPLE AND P. BURGARDT

ABSTRACT. Substantial increases in GTA weld depth/width ratio resulted from small additions of sulfur dioxide (SO_2) to the torch shielding gas when welding two stainless steels. The improvement was demonstrated on both Types 304 and 21-6-9 austenitic stainless steels, but would be expected for iron-base alloys generally. The weld pool shape achieved was essentially independent of variations in both SO_2 content of the torch gas and base metal composition when SO_2 in the shielding gas was in the range of 500 to 1400 ppm. With 700 ppm SO_2 in the torch gas, less than 30 ppm sulfur was added to an autogenous weld bead. For alloys where this additional sulfur can be tolerated and appropriate measures can be taken to handle the toxic SO_2, this technique offers a promising way to improve GTA weld joint penetration while suppressing variable penetration.

Introduction

The shape of GTA welds has long been of concern, in part because the GTA welding process tends to be used in applications where high quality, high precision welds are required. Furthermore, the welds are often made by automatic equipment, which is presently unable to compensate for variability in weld pool geometry once the welding variables have been set. For these reasons, considerable interest has been generated by the observations that weld shape, especially joint penetration, can vary substantially between different heats (and even within the same heat) of material with the same nominal composition.

Heiple and Roper (Ref. 1) have recently proposed a mechanism for the origin of variable GTAW joint penetration by which weld pool shape can be substantially altered by variations in the concentration of certain trace elements in the weld pool. They proposed that the major factor determining weld shape is generally fluid flow in the weld pool and that, under many common GTA welding conditions, the major factor driving fluid flow is a surface tension gradient. Trace elements affect weld pool shape by altering surface tension gradients, thereby changing the magnitude and/or direction of fluid flow in the weld pool.

For pure metals and many alloys, the surface tension decreases as temperature increases (Ref. 2). For weld pools in such materials, the surface tension will be greatest on the coolest part of the pool surface at the edge, and lowest on the hottest part under the arc near the center of the pool. Such a surface tension gradient produces outward surface fluid flow (as shown schematically in Fig. 1A) and generates a relatively wide and shallow weld.

Surface-active trace elements, when present in sufficient quantity in the weld pool, create a positive surface tension temperature dependence (Ref. 2). Under these conditions, the surface tension will be highest near the center of the weld pool and an inward surface fluid flow results (as shown schematically in Fig. 1B).

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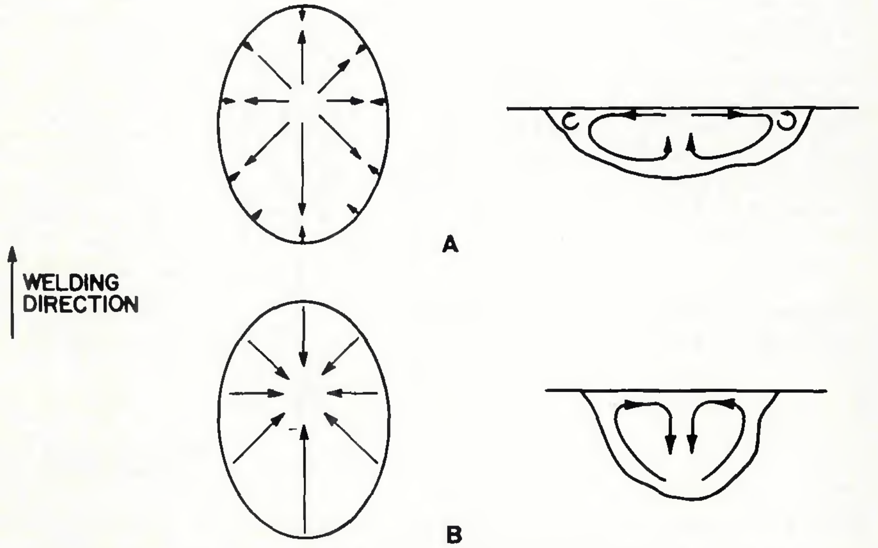

Fig. 1 — Proposed (Ref. 1) surface and subsurface fluid flow in the weld pool. A — surface tension temperature coefficient negative; B — surface tension temperature coefficient positive

This fluid flow pattern produces relatively deep, narrow weld beads.

In iron-base alloys, sulfur and oxygen are the surface-active trace elements most commonly present. Historically, sulfur and oxygen levels have been high enough so that complete joint penetration was observed consistently, *i.e.,* weld depth/width (d/w) ratios of about 0.5. However, improvements in steelmaking practice have made available steels, particularly stainless steels, which have extremely low sulfur and oxygen contents (less than 10 ppm each). Such steels exhibit poor joint penetration in GTA welding and can have weld d/w ratios as low as 0.15. These wide, shallow weld pools create a number of significant welding problems.

One approach to improving GTAW joint penetration and reducing variable joint penetration is to add small concentrations of surface active elements to the weld pool. This can be accomplished in a number of ways, including the addition of a doped filler metal wire to the weld pool, coating the joint prior to welding, and doping the shielding gas delivered through the torch. The additions need to be small, since most elements known to be surface active in iron (S, Se, and Te) promote hot cracking. We report here the effects of small SO_2 shielding gas additions on GTA welds on 21-6-9 and 304 austenitic stainless steels.

Experimental

The initial experiment consisted of producing GTA bead-on-plate welds on a 25 mm (1 in.) thick plate of 21-6-9 stainless steel. Since the intent of the experiment was to determine if SO_2 additions to the torch gas would improve weld d/w ratio, a plate with known-poor d/w ratio was used. The composition of the plate is given in Table 1. All welds were made under identical welding conditions except that the torch gas composition was varied between pure argon and argon containing 2000 ppm SO_2. The welding was performed in a large chamber filled with argon. The SO_2 content in the shielding gas was varied by mixing pure argon with gas from a second cylinder containing argon with 2000 ppm SO_2.

Table I—Analysis of 21-6-9 Plate, wt-%

Cr	20.1
Ni	6.8
Mn	8.7
N_2	0.27
C	0.025
Al	0.0058
O_2	0.0058
S	0.0024
Fe	balance

The second experiment was designed to determine if variable joint penetration could be suppressed with SO_2 shielding gas additions. Strips in a 17 mm (0.67 in.) thick plate of 304L stainless steel were doped with either sulfur or selenium, and GTA welds were subsequently passed across the doped zones and undisturbed base metal. The doping technique involved electron beam melting foils of 303 stainless steel (for sulfur doping) and 303 Se stainless steel (for selenium doping) into the base plate. The addition of sulfur (Ref. 3) and selenium (Ref. 4) to stainless steel is known to drastically increase GTA weld d/w ratio when the steel has an initially low d/w ratio. The doping procedure has been described in detail previously (Ref. 5). The 304L plate used in this experiment had an exceptionally low sulfur and oxygen content and exhibited a d/w ratio of about 0.17. The composition is given in Table 2. It was chosen to give the largest possible difference in weld shape between the doped zones and undoped base metal. The welding conditions for both the experiment with varying SO_2 shielding gas content and the experiment with doped base metal were: current — 150 A DCEN; electrode to work distance — 2 mm (0.080 in.); travel speed — 150 mm/min (6 ipm); electrode tip angle — 45 degrees; and shielding gas flow rate — 0.57 m^3/hr (20 cfh). Finally, both autogenous welds and welds with cold filler metal addition were made on several joint configurations to confirm that the changes observed in bead-on-plate welds would also be seen in full joint penetration welds.

Table 2—Analysis of 304L Plate, wt-%

Cr	19.0
Ni	10.3
Mn	1.9
C	0.034
Al	0.002
O_2	0.001
S	0.002
Fe	balance

Results

SO_2 in the shielding gas had a substantial effect on weld pool shape. Weld d/w ratio is plotted versus torch gas SO_2 content in Fig. 2. Cross sections of welds made using pure argon and 750 ppm SO_2 are shown in Fig. 3. One of the encouraging aspects of the results presented in Fig. 2 is that there is a substantial range (approximately 500-1400 ppm) of SO_2 contents for which the d/w ratio is independent of SO_2 concentration. This can

Table 3—Sulfur Contents of Welds on 21-6-9, ppm

Argon Shield	Argon + 750 ppm SO_2	Argon + 2000 ppm SO_2
40	67	150

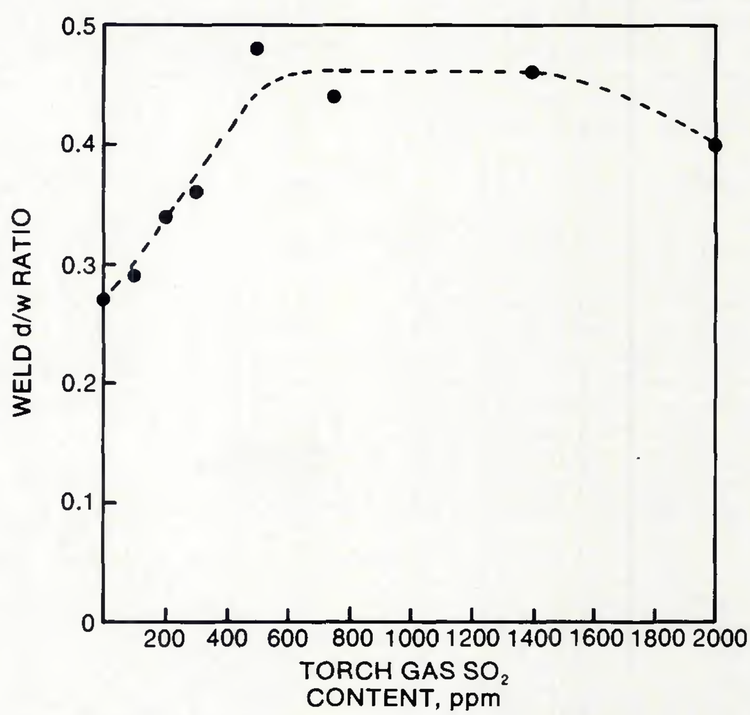

Fig. 2 — Effect of sulfur dioxide in the shielding gas on GTA weld depth/width ratio. 21-6-9 stainless steel

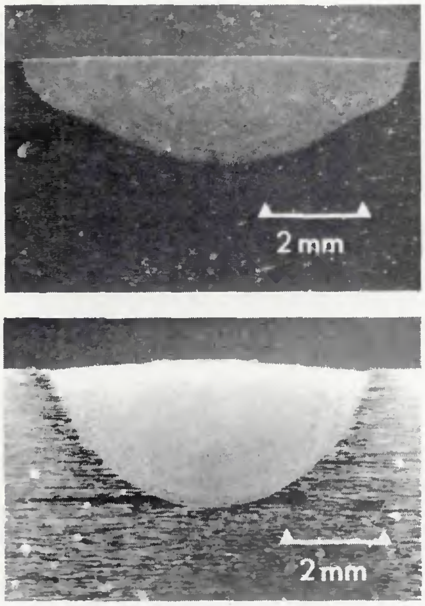

Fig. 3 — Cross sections of GTA welds made with (top) pure argon shielding gas and (bottom) argon plus 750 ppm SO_2 shielding gas

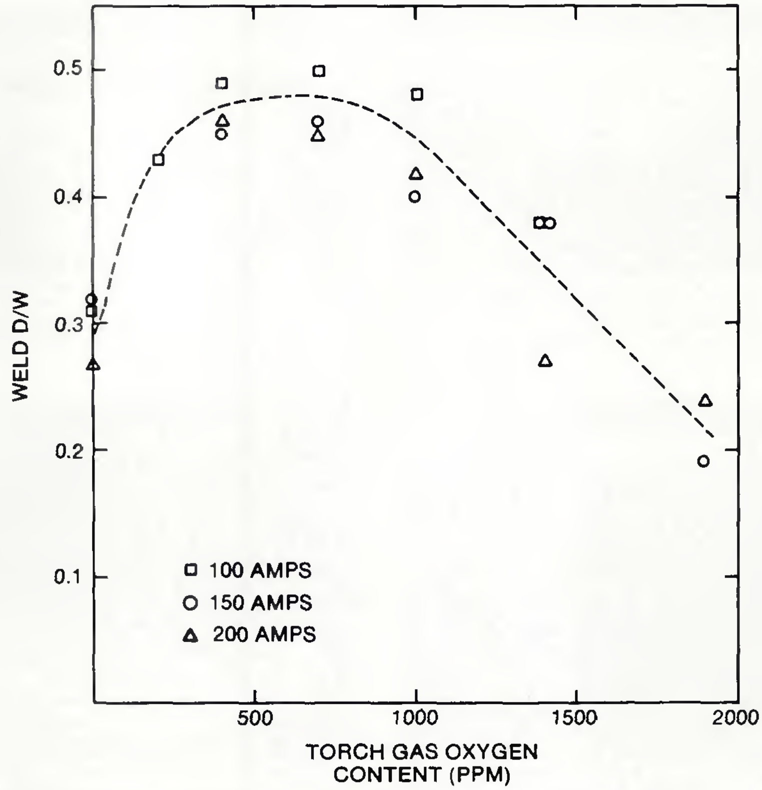

Fig. 4 — Effect of oxygen in shielding gas on GTA weld depth/width ratio (Ref. 6)

be contrasted with the results obtained in a similar experiment when oxygen was added to the shielding gas, where a relatively sharp maximum in d/w ratio is obtained with increasing oxygen concentration — Fig. 4. Welds made with shielding gas of pure argon, 750 ppm SO_2, and 2000 ppm SO_2 were cut from the plate and analyzed for sulfur and oxygen. The measured sulfur contents of the welds are given in Table 3. Very little oxygen was added to the weld; the increase was only 25 ppm with 2000 ppm SO_2 in the shielding gas.

The results of the second experiment, to determine if variable joint penetration would be suppressed by SO_2 shielding gas additions, are shown in Fig. 5. Base metal containing welds with d/w ratios, which differed by a factor of more than two with argon shielding, exhibited nearly identical weld shape when welded with 700 ppm SO_2 in the shielding gas. Thus, the same weld pool shape can be achieved independent of base metal chemistry variations.

The dramatic increase in bead-on-plate weld d/w ratio observed when SO_2 was added to the shielding gas was also observed for welded joints. Figure 6 is a cross section of a welded butt joint in which a portion of the weld (Fig. 6A) was produced using argon shielding gas and the other portion (Fig. 6B) was made using 700 ppm SO_2 in the shielding gas. Similar results are obtained in welds with cold filler metal addition — Fig. 7. In both cases, the other welding variables were the same for both sections of the weld.

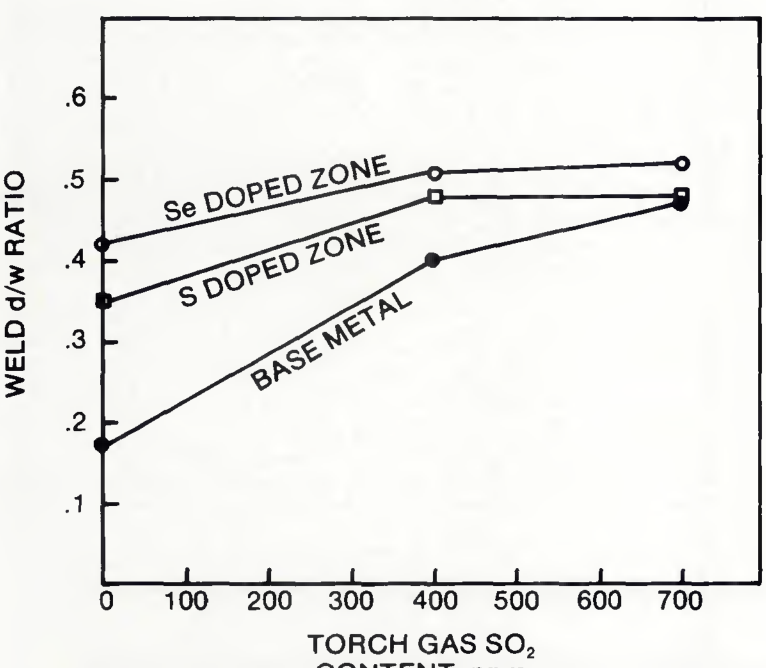

Fig. 5 — Effect of shielding gas SO_2 content on the changes in GTA weld depth/width ratio caused by 304L base metal chemistry variations

Discussion

Previous work has demonstrated that sulfur and other surface-active element additions increase the d/w ratio of GTA welds on ferrous alloys (Ref. 3). The increase is predicted by the surface tension-driven fluid flow model (Ref. 1) and arises from changes caused by the surface-active elements in surface tension gradients. Sulfur is generally undesirable in steels, causing or contributing to (among other things) increased inclusion

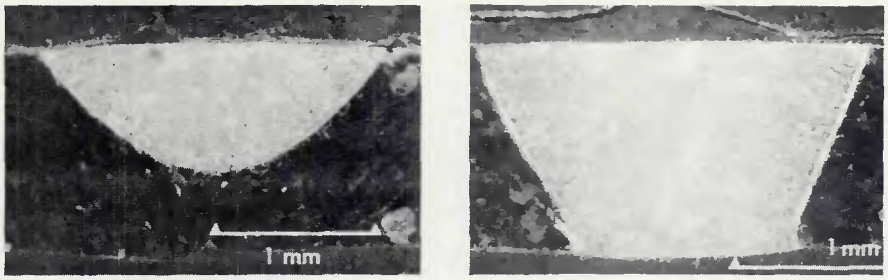

Fig. 6 — Welded butt joints on 304L stainless steel with (left) pure argon and (right) argon plus 700 ppm SO_2 shielding gases. All other welding variables were unchanged; the SO_2 was simply turned off when the weld was partially completed. Current — 47 A; travel speed — 200 mm/min

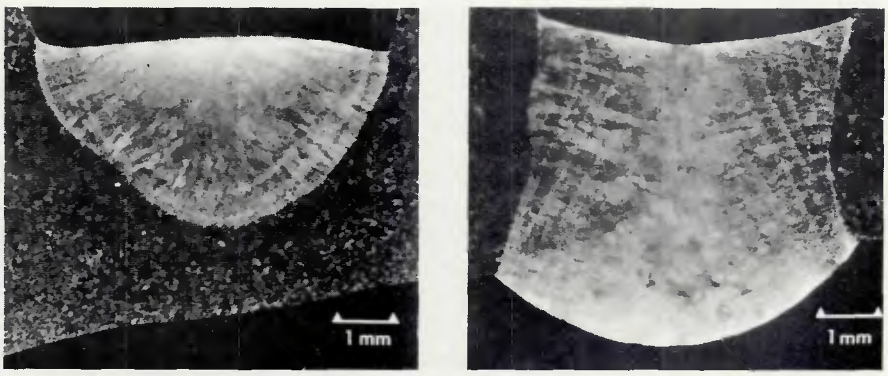

Fig. 7 — Welded butt joints on 304L stainless steel using 308 filler metal wire with (left) pure argon and (right) argon plus 700 ppm SO_2 shielding gases. All other welding variables were unchanged; the SO_2 was simply turned off when the weld was partially completed. Current — 163 A; travel speed — 130 mm/min; feed speed of 0.045 in. wire — 750 mm/min

content, hot cracking and reduced toughness. There has therefore been a major effort, with considerable success, to lower sulfur levels in steels. Unfortunately, this can lead to significant GTA welding problems. The addition of small concentrations of sulfur to the weld pool offers one approach to solving the welding problem without raising the general sulfur level in the steel. Mixing about 700 ppm SO_2 in shielding gas for GTA welding improves joint penetration substantially in austenitic stainless steel, eliminates the sensitivity to minor variations in base metal trace element content, and adds less than 30 ppm sulfur to the weld. Where this additional sulfur can be tolerated, this technique appears to be a promising approach to eliminating poor and variable joint penetration in GTA welding.

There are potentially significant problems in using SO_2 in the weld shielding gas. Sulfur dioxide is toxic, with permissible concentrations (Ref. 7) far below the levels required for welding. Provisions to safely remove the gas are therefore required. It is also an environmental hazard and, if used in significant quantities, would require treatment. The weld bead surface is discolored when welding is performed with SO_2 in the shielding gas, which may be unacceptable for certain applications, although the surface is easily cleaned. In the limited number of experimental welds so far attempted, there has been no unusual deterioration of the tungsten electrode noted; however, it is possible that electrode life would be reduced in a production welding operation. Finally, argon-SO_2 mixtures are not at present routinely available, although they can be obtained commercially.

Conclusions

The addition of small concentrations of SO_2 to the normal argon shielding gas drastically improves the GTA weld d/w ratio (increases joint penetration) on 304L and 21-6-9 stainless steels with initially poor joint penetration characteristics. Furthermore, if heats of stainless steel with joint penetration characteristics that differ when welded in argon are welded with SO_2 in the torch gas, the joint penetration is improved and the weld shape is essentially indistinguishable for the different heats. Similar results are anticipated for other stainless steels and ferrous alloys, generally. The maximum benefit from SO_2 additions is achieved between about 500 and 1400 ppm. Under a common GTA welding condition (150 A, 150 mm/min/6 ipm travel speed), less than 30 ppm sulfur is added to the 21-6-9 stainless steel when there is 700 ppm SO_2 in the shielding gas. When appropriate measures to handle the toxic SO_2 can be taken, this technique offers a promising way to improve joint penetration in GTA welding and to suppress variable joint penetration. The only torch gas dopants which we have tested are oxygen and SO_2; however, it is possible that other dopants could be found which would be as successful or, more so.

Acknowledgment

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