TREND IN CONTROLLING PENETRATION PROFILE IN GTA WELDING

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The weldpool geometry has a large bearing on the quality of the GTA welds. It is affected by the welding current, the shielding gas composition and the presence of trace elements. There is also an inherent variability in the weldpool geometry, particularly in the automatic GTA welding process. The need for improving penetration and neutralising the inherent variability have led various researchers to work on the effect of shielding gas and introduction of minor elements in some metals and alloys on the weldpool geometry. This paper reviews the relevant published literature on controlling penetration in GTA welding.

INTRODUCTION

The second and the third quarter of the present century can be considered as the golden era of the developments in the field of welding technology. During this period, many new welding processes, consumables and equipment have been commercialised. One such process is the gas shielded tungsten arc (GTA) welding, patented initially in the early thirties in the USA and subsequently put to industrial use in the forties. It came into the market primarily to :

a) cope up with the difficult task of welding highly oxidisable metals and alloys as well as stainless steels.

b) get clean welds free from entrapped slag and flux residue (as with MMAW and SAW), and

c) have a better control over the weld by using a concentrated heat source with a nonconsumable tungsten electrode.

Since then, its area of application has extended to cover C-Mn steels, alloy steels, stainless steels and nonferrous metals such as copper, titanium, zirconium, etc. for fabrication and repair welding. One of the driving forces for the present level of development is the amenability of GTA welding to automation. This feature has been fully exploited making it ideal for joining of critical components, particularly those requiring low heat input.

The shape of the GTA welds affects the quality and the precision of the job. The depth of penetration in GTA welding is normally shallow and is less than that in MIG and SAW processes. Moreover, the minor inherent variations in the arc characteristics may affect the weld shape (1) and the welds made by automatic GTA process are normally unable to compensate for the inherent variability in the weldpool geometry. Such a situation is not acceptable for precision joints and hence there has been a search for solutions capable of making the weld free from variable penetration profile.

WELD SHAPE

In the search for conditions ensuring predictable and reproducible weld shape which are critical in high precision automated welding applications, a new finding came to light. In numerous instances, variations in GTA weld shape among different heats of materials having the same nominal composition and using identical welding parameters were obtained (1-2, 4-12). It has been reported that the weld shape, as measured by the depth to width ratio (dlw) can vary even by more than a factor of two. The variations in the weld shape has been traced to differences in the residual element in the range of 50 to 100 ppm of the materials being welded. It is largely accepted that the GTA weld pool shape is determined by the fluid flow patterns existing in the weld pool during welding. The dominant force responsible for the weld pool fluid flow is the surface tension gradient. Surface active trace elements, present in the base metal and/or coming from the shielding gas/filler rod, which segregate to the liquid surface, may lower the surface tension and change the temperature dependence of the surface tension and thereby modify the surface tension gradient.This, in turn, changes the fluid flow in the weld pool and thus the weld shape.

The surface tension gradients can also be altered by changing the temperature gradients on the weld pool surface. The magnitude of the surface temperature gradient is determined by the heat input to the weld as well as its distribution so that the temperature gradients can be varied by changing the welding parameters. While the input power is a function of the welding current and the arc voltage (which in turn is dependent on the shielding gas composition), the distribution of the input power is a function of the concentration and shape of the heat source. The factors which affect the surface tension gradient are the shielding gas, the electrode shape and size, and the presence of the active and residual elements.

Shielding Gas

In the GTA welding process, usually the shielding gas is an inert gas like argon or helium(3). Sometimes for some specific reasons, an active gas like hydrogen, oxygen, nitrogen or carbon dioxide is also used along with argon and/or helium. The shielding gas is selected according to the material being welded and the penetration pattern desired. For example:

a) Commercially Pure argon is frequently used as a shielding gas in GTA welding of austenitic stainless steels. It gives a clean weld metal, and the arc and the weld pool are stable. The penetrating power of the arc is, however, rather weak.

b) Helium and helium-argon mixtures, typically 70/30 helium/argon, have several advantages including higher rate of heat input and hotter arc. The greater rate of heat input is caused by the higher ionisation potential of helium which is approximately 25eV compared with 16eV for argon. This fact is responsible for promoting higher welding speed (helium can give 160% higher welding speed than argon) and producing an improved weld bead penetration profile. The disadvantages of using helium include high cost (cost of helium is roughly three times that of argon) and the difficulty in initiating the arc.

c) The penetrating power of argon can also be improved by adding hydrogen to argon, typically 2 to 25% hydrogen. Argon-hydrogen mixtures can be used for welding mild steel, austenitic stainless steel and nickel alloys. The advantages of adding hydrogen to argon are that the shielding gas is slightly reducing, can produce clean welds and make the arc more constricted, thus enabling higher speeds to be achieved (the speed increases by about 80% with 5% addition of hydrogen to argon) and/or producing an improved weld bead penetration profile (that is, greater depth to width ratio).But the use of hydrogen gas proffers the risk of hydrogen induced cracking in carbon and alloy steels, and weld metal porosity in metals such as ferritic steels, aluminium, copper and magnesium based alloys. Hydrogen increases the arc voltage by 10 to 20% and thus makes the arc hotter. A higher voltage is desirable for welding thicker sections and materials of higher thermal conductivity.

d) Nitrogen and nitrogen-argon mixtures (upto 50% nitrogen) make the arc extremely hot and hence are beneficial when welding copper. It helps in overcoming the chilling effect of the material.

e) The use of oxygen or its gaseous compounds mixed with a conventional shielding gas like argon, offers a simple method of improving the shallow penetration of austenitic stainless steels. The optimum contents of oxygen, carbon dioxide, or sulfur dioxide in argon varies from about 0.05 to 0.30% resulting in the d/w ratio varying from 0.4 to 0.6. Lower or higher contents generally result in lower d/w ratios. One hindrance of using these active gases is the oxidation potential of the tungsten electrode. It is believed that the surface tension of the weld pool is modified by oxygen (or oxygen dissociating from other gases) and this affects the weld pool profile.

Residual Element

It has been observed that chemical variations from cast-to-cast introduce variations in weld bead shape and penetration during mechanised autogenous GTA welding of materials nominally to the same specification using pure argon as the shielding gas (1-2, 4-12). In some cases, a variation of d/w from 0.12 to 0.25 has been reported in austenitic stainless steels. It is, therefore, a matter of concern. It has been established that the melting variability may introduce small differences in the chemical compositions (at micro level) between heats of the same type of austenitic stainless steel. Any minor difference in some of those elements such as S, O, Al and Ca have been found to affect significantly the weld penetration. For example, as the amounts of S and O in the base metal increase, the d/w ratio increases (that is, the weld penetration increases and the bead width decreases). Similarly, as the percentages of Al and Ca increase, weld penetration decreaes and the bead width increases.

Most literature on variable weld penetration agrees that S has the dominant effect on penetration. As a general rule, S begins to have a detrimental effect on weld penetration in austenitic stainless steels at levels less than 0.01 weight% (100 ppm) with the effect of dramatically increasing with levels below 60 ppm. Similarly, selenium in 304L stainless steel has also been found to affect the d/w ratio significantly (Fig.1). It has also been earlier mentioned that introduction of oxygen (say through the shielding gas) can also increase the d/w ratio. Thus it can be said that the actual weld penetration will depend on the combination of trace elements present in a specific material, heat and the shielding gas composition.

Attempts to minimise the effects of the chemical composition variability on the weld penetration profile in the mechanised GTA welding have led some researchers to try to use some doping elements through a suitably formulated 'flux' with the idea that the resultant penetration will be high to compensate for any variability associated with the trace elements. The concept of using a 'flux' with GTA welding to increase penetration was first introduced by the Paton Welding Institute in the Ukraine. Some of the fluxes have been made by mixing inorganic powders suspended in a volatile liquid media (such as acetone, methanol or methyl-ethyl-ketone). This has revolutionised the process of GTA welding.

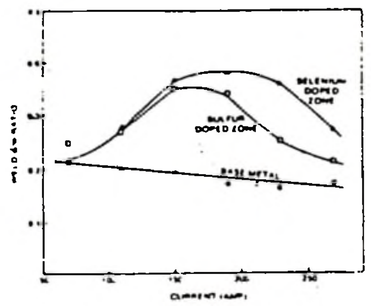

Fig 1. GTA weld d/w ratio versus weld current for low sulfur 304L stainless steel (20 ppm) base metal as well as sulfur and selenium doped zones. (Ref. 12).

CONCLUSION

There has been revolutionary developments in the GTA process in the recent years. It is leading to a welding process with capability to produce ultrahigh quality welds with consistent weld shape.

REFERENCES

1. C.R.Heiple and J.R.Roper, "Effect of Selenium on GTAW Fusion Zone Geometry", Welding Journal, Vol. 60, No. 8, Aug 1981, pp 143-s to 145-s.
2. Englewood Cliffs, "Welding-Theory and Practice", Published by

Prentice Hall, New Jersey, pp 13-21.

3. J. I. Leinonen and L.P.Karjalainen, "Unexpected Weld Pool Profiles in GTA Welding with Oxidizing Shielding Gas", Recent Trends in Welding Science and Technology, ASM International, Materials Park,Ohio, 1990, pp 387-389.

4. J. L. Robinson and T.G.Gooch, "Effects of Composition and Physical Properties on GTA Weld Penetration of Austenitic Stainless and Low Alloy Steels", Ibid., 1990, pp. 403-406.

5. W.H.Chen, P.Banerjee and B.A.Chin, "Study of Penetration Variations in Automated Gas Tungsten Arc Welding", Ibid., 1990, pp 517-522.

6. T.Paskell, C.Lundin and H.Castner, "GTAW Flux Increases Weld Joint Penetration", Welding Journal, Vol. 76, No. 4, April 1997, pp. 57-62.

7. C.R.Heiple and J.R.Roper, "Mechanism for Minor Element Effect on GTA Fusion Zone Geometry", Welding Journal, Vol. 61, No. 4 April 1982, pp. 97-s to 102-s.

8. C.R.Heiple, J.R.Roper, R.T. Stagner, and R.J.Aden, "Surface Active Element Effects on the Shape of GTA, Laser, and Electron Beam Welds", Welding Journal. Vol. 63, No. 3, March 1983, pp. 72-s to 77-s.

9. J.F.Lancaster and R.C.Mills, "Recommendations for the Avoidance of Variable Penetration in Gas Tungsten Arc Welding", Abington Publishing, Cambridge, England [Referred by T. Paskell et. al. (6)].

10. J.A.Lambert, "Cast-to-cast Variability in Stainless Steel Mechanised GTA Welding". Welding Journal, Vol, 70, No. 5, May 1991, pp. 41-52.

11. B. Pollard, "The Effects of Minor Elements on the Welding Characteristics of Stainless Steel", Welding Journal, Vol. 67, No. 9, Sept. 1988, pp. 202-s to 213-s.

12. C.R.Heiple, P.Burgardt and J.R.Roper, "Control of GTA Weld Pool Shape". Advances in Welding Science and Technology, ASM International, Materials Park, Ohio, 1990, pp. 387-391.