

Gas Tungsten Arc Welding Electrodes for Stainless Steels

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When inert gas shielded arc welding was introduced nearly 60 years ago few would have imagined the impact the process, and in particular the non-consumable electrode version, would have on the fabrication industry world-wide. The tungsten arc welding concept was rapidly adopted from the 1950s and made a pivotal contribution to the development of stainless steels for the nuclear, chemical and aerospace technologies. It is arguably now established as the most versatile technique for producing fusion welds to the highest quality standards.

Since a temperature of around 4000 °C is generated in the arc during welding, the role played by the electrode is crucial. Clearly it must have a high melting point and it must be non-consumable: tungsten quickly established itself as the most suitable material. As the knowledge of arc characteristics increased it became clear that the use of pure tungsten presented some limitations on process development, particularly arc initiation and stability. Early studies on the effect of minor additions of refractory oxides, notably thoria, to the tungsten showed that significant overall improvements in performance could be realised and from this work a range of tungsten electrodes containing oxide additions or 'dopants' were introduced progressively.

Notwithstanding the potential significance of electrode characteristics, the last 50 years has witnessed the publication of few scientific papers of practical use. Some of these advocate the widespread use of dopants on the basis of improved welding performance, some highlight the hazards associated with them. Much of the work is however contradictory and contentious. Many field trials have also been undertaken by suppliers and users and claims made for the superiority of some dopants over others. The evidence supporting the results of these trials is flawed however and cannot be used as the basis on which to make generalised conclusions. Here we present an objective review of what has become an emotive issue – the use of dopants in tungsten electrodes.

The issues under examination fall generally into two categories; those associated with technical and commercial advantages, and those relating to health hazards.

Electrode manufacture

Electrodes are made using a metallurgical process in which powder is compressed under high temperature and pressure to produce rods. The oxide additives are generally dispersed finely in the tungsten prior to forming but some products – composite electrodes – are made up of a tungsten core with an oxide coating.

The principal dopants

A major advantage of tungsten as a welding electrode material is its low work function – the energy needed to remove an electron. This is an essential requirement for efficient arc generation. Dopants reduce the work function and thus enhance electron emission. As a consequence this increases the usable life of the electrode and may also promote arc initiation and stability.

Material	Work function (electron volts)
Pure Tungsten	4.5
Thoria	3.35
Lanthana	3.3
Ceria	2.6

The most commonly used additives are thoria (ThO_2), zirconia (ZrO_2), lanthana (LaO_2), yttria (Y_2O_3), magnesia (MgO) and ceria (CeO_2) and some of these are classified in Table 1^{1,2,3}. The commercial manufacturers also produce a range of electrodes which incorporate a combination of dopants⁴.

Technical and Commercial Considerations

Arc Starting

Although the electrode material has a considerable influence on the ease with which an arc can be initiated there exist several other controlling factors. Among these are arc gap, tip geometry, open circuit voltage, welding current, shielding gas and the characteristics of the welding power source.

With so many interacting variables, experimentation is time-consuming. The relative arc starting performance of any one electrode varies with other parameters; the most difficult starting conditions prevail with low open circuit voltage ie $< 35 \text{ V}$, low current ie $< 20\text{A}$ and long arc gap. Castner⁵ reported that a 2% ceria electrode offered the best performance but Matsuda⁶ found that at low open circuit voltages ceria was inferior to lanthana, yttria and thoria. Specific but limited work⁷ on a multi-dopant electrode concluded that there was little difference in arc starting compared with a 2% thoria electrode.

Review Summary: There is little to choose between the effect of various doped electrodes on arc starting but none of them is any worse overall than pure tungsten. Under certain defined conditions lanthana and ceria offer significant advantages.

Arc Stability

A stable arc is a prerequisite for producing welds of consistently high quality. Stability is inversely related to the electrode material work function so that although

tungsten is good, additions of dopants with their lower work functions increases arc stability. There is evidence ⁵ that some dopant materials are lost from the electrode surface however and may or may not be adequately replenished by diffusion from the body of the electrode. This would have the net effect of progressively reducing arc stability during use.

Review Summary: Addition of any refractory oxide dopant improves arc stability but ceria is the most effective.

Electrode Erosion

As with arc starting, erosion is influenced by many related variables; even sophisticated research must therefore lead to conclusions based on limited combinations of circumstances.

A major contributory factor is contamination through touch starting and contact with the weld pool. Other factors are electrode tip geometry, welding current, open circuit voltage, shielding gas, parent material and welding power source.

Anderson ⁷ showed that dopant additions can reduce erosion at high current levels but the conclusion is based on limited work. Huntingdon Fusion Techniques ⁸ has shown that multi-doped electrodes perform better than those containing only zirconia under most circumstances on aluminium but again the work is limited. Winson & Turk ⁹ reported that thoria doped electrodes exhibited longer life than pure tungsten in most applications. Matsuda ⁶ found that dopant additions offered significant advantages at higher welding currents. Erosion by evaporation is an important consideration and the fact that refractory oxides reduce the temperature of the electrode during welding ^{6,9} suggests that oxide additions would reduce evaporative losses: the effect of diffusion referred to earlier must be considered however.

Review Summary: Dopant additions of all types reduce electrode erosion under some circumstances but no single dopant is superior to the others under all welding conditions.

Weld quality considerations

The welding electrode plays a major part in ensuring consistency of operation since it influences stability of the arc. Whilst low cost tungsten and oxide doped tungsten electrodes are available commercially they are usually of low quality: in particular the operational consistency is poor.

Review Summary: Weld quality can be influenced by electrode quality

Health Hazards

Health warnings are issued ^{1, 2, 3, 12, 13} by many legislative and advisory bodies in connection with the use of welding electrodes which contain refractory oxides. The warnings refer to the potential toxicity and in particular to the risk of inhalation of dust particles from thoria-containing electrodes generated during grinding. The general hazard may be put in subjective context by referring to the specifications for doped electrodes listed in Table 1. Whilst all these electrodes may contain radio-toxic substances, the level of risk is substantially less with those containing zirconia, lanthana and ceria than with those containing thoria.

Whilst the use of thoria-doped electrodes has not been banned there is a duty of care responsibility on the suppliers and users of these products to take adequate precautions during storage and use.

Use

Local exhaust ventilation should be provided where occasional electrode tip grinding is carried out and any surface dust removed regularly by vacuum cleaning. Volume production welding with thoria-doped electrodes may necessitate the use of a dedicated tip grinding facility. In these circumstances a system of work based on exhaust and respiratory aids, with suitable arrangements made for subsequent disposal of the dust ¹² should be implemented.

Review Summary: The use of thoria-doped electrodes constitutes a health risk. The alternative oxide-doped electrodes are comparatively safe.

Conclusions

With respect to arc starting, all oxide-doped electrodes perform better than pure tungsten electrodes. Under certain defined conditions lanthana and ceria offer significant advantages.

Addition of any refractory oxide dopant to tungsten electrodes improves arc stability but ceria is the most effective.

Dopant additions of all types reduce electrode erosion under some circumstances but no single dopant is superior to the others under all welding conditions.

Electrode quality can be an important consideration.

The use of thoria doped electrodes constitutes a health risk and alternative oxide doped electrodes should be employed.

References

- 1 British Standard 6678:1986
Tungsten electrodes for inert gas shielded arc welding and for plasma cutting and welding
- 2 ISO 6848-1984
Tungsten electrodes for inert gas shielded arc welding and for plasma cutting and welding
- 3 British Standard BS EN 26848-1991
Specification for tungsten electrodes for inert gas shielded arc welding and for plasma cutting and welding
- 4 Multi-Strike Tungstens
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New Developments in Gas Tungsten Arc Welding Electrodes
Edison Welding Institute
- 6 Matsuda et al
Study on Gas Tungsten Arc Electrode
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- 7 Anderson P C J
Performance of TIG Electrodes
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- 8 Huntingdon Fusion Techniques
Manual Welding Trials with Multi-Strike Tungstens on Aluminium
Site Trials May 1999
- 9 Winson & Turk
A Comparative Study of Thoriated, Zirconiated and Pure Tungsten Electrodes
Welding Journal Res Supp March 1957
- 10 American Standard ANSI/AWS A5 12-92
Specification for tungsten and tungsten alloy electrodes for arc welding and cutting
- 11 The Health and Safety Executive HSE 564/6 (Rev)
Storage and use of thoriated tungsten electrodes

- 12 The Health and Safety Executive: Guidance note EH53
Respiratory protective equipment for use against airborne radioactivity
- 13 European Council Directive 90/394/EEC
Protection of workers from the risks related to exposure to carcinogens at work.

Table 1
Classification of tungsten electrodes (from BS 6678)

Code	%	Dopant type	Identification Colour
WP	none	none	green
WT 4	0.35 - 0.55	thoria	blue
WT 10	0.80 – 1.20	thoria	yellow
WT 20	1.70 – 2.20	thoria	red
WT 30	2.80 – 3.20	thoria	violet
WT 40	3.80 – 4.20	thoria	orange
WZ 3	0.15 – 0.50	zirconia	brown
WZ 8	0.70 – 0.90	zirconia	white
WL 10	0.90 – 1.20	lanthana	black
WC 20	1.80 – 2.20	ceria	grey