International Scientific-Technical and Production Journal

The Paton WELDING JOURNAL

November 2010 # 11

English translation of the monthly «Avtomaticheskaya Svarka» (Automatic Welding) journal published in Russian since 1948

Founders: *E.O. Paton Electric Welding Institute of the NAS of Ukraine*
International Association «Welding»

Publisher: *International Association «Welding»*

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State Registration Certificate
KV 4790 of 09.01.2001

Subscriptions:
$324, 12 issues per year,
postage and packaging included.
Back issues available.

CONTENTS

EFFECT OF NANOFOIL OF THE Ni–NbC SYSTEM ON STRUCTURE OF ELECTRON BEAM WELDS IN HEAT-RESISTANT ALLOYS

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The effect of niobium carbide nanoparticles on structure and properties of electron beam welds in nickel alloys was studied. Alloying of the weld metal with niobium carbide nanoparticles was performed by adding composite nanostructured foil of the Ni–NbC system into the weld pool. The foil was produced by electron beam evaporation of the components in vacuum, followed by combined deposition of their vapour flows on the substrate. Adding the niobium carbide nanoparticles into the weld pool was shown to lead to formation of crystalline grains with a cellular structure within the weld zone, with the NbC particles located along the boundaries of the above grains. The effect of this structure of the welds on their mechanical properties was analysed.

Keywords: *electron beam welding, electron beam evaporation, nickel alloy, weld, foil, alloying, modification, niobium monocarbide, nanoparticles, intragranular substructure*

Main difficulties in welding heat-resistant precipitation-hardening nickel-base alloys are associated with the need to prevent hot cracking of the welds and provide the welded joints with a required set of mechanical, technological and service properties. One of the ways of addressing these problems is optimisation of alloying of the weld metal. The alloying elements of choice in this case are those that improve high-temperature ductility of the weld (even at the expense of decreasing its strength compared to that of the base metal). Cracking of the weld metal and HAZ can be avoided by adding molybdenum, vanadium, cobalt, manganese, titanium, boron, rhenium, hafnium and yttrium, as well as their borides, oxides and carbides to the weld metal, and by controlling the welding process [1–5].

However, traditional methods used for alloying the welds have a number of drawbacks. For example, alloying the weld metal with molybdenum and tungsten decreases high-temperature corrosion resistance, presence of boron reduces heat resistance, and adding rhenium, hafnium and yttrium is difficult to implement in terms of technology. In this connection, optimisation of a method of alloying the weld metal in welding heat-resistant precipitation-hardening nickel alloys is a problem of current importance.

One of the most common metallurgical methods for preventing hot cracking is refining of structure of the weld metal and HAZ by alloying the weld pool with modifiers [6–8]. Adding small amounts of nitrides, carbides, oxides and other elements promotes formation of fine-grained structure of the weld metal owing to heterogeneous solidification [9]. Modification also contributes to the intensity of the diffusion processes in the melt and promotes lowering of the level of liquation in the weld metal [7].

Positive results were obtained from using thin composite foils consisting of components of a nanosized scale as a filler metal in fusion welding or as a transition element in pressure welding [10, 11]. Such foils produced by combined condensation of various components from the vapour phase and containing nanoparticles provide activation of the diffusion processes during welding [12–15]. Supposedly, adding refractory nanoparticles to the weld pool will also promote increase in the number of solidification centres and, eventually, grain refining, formation of equiaxed structure and uniform distribution of alloying elements in the weld metal.

By an example of model materials (nickel), this study considers the possibility of modifying structure of the welds by using fillers in the form of foils that contain nanosized carbide phases, and gives estimation of strength properties of the resulting welded joints.

Pure nickel being the base of heat-resistant alloys was used as a model material to evaluate the effect of nanoparticles added to the weld pool on structure of the weld metal. Chemical composition of alloying filler metals was selected allowing for the requirement of filler and base metal matching. From this standpoint, the preference was given to niobium monocarbide, which is characterised by high thermodynamic stability and used as a structural component of many heat-resistant alloys.

The filler metal based on a composite of the Ni–NbC system in the form of foil 50–150 μm thick was produced by electron beam evaporation of components in vacuum using two ingots, followed by combined deposition of their vapour flows on the substrate at a preset temperature. The flow diagram of the deposition process is given in [10, 11]. A layer of CaF_2 was