ABSTRACT

Two important nickel base alloys that are used for high temperature applications are Inconel 617 and Inconel 718. Inconel 617 is a solid solution strengthened nickel alloy with chromium, cobalt and molybdenum as the main alloying elements. This alloy has a good combination of high temperature strength, corrosion resistance and oxidation resistance. Inconel 718 is an age hardenable nickel alloy with chromium, iron, niobium and molybdenum as the main alloying elements. This alloy has high strength and corrosion resistance and is used for high temperature applications upto 700^0C.

Hot cracking is an important metallurgical problem in arc welding of many nickel base alloys. Inconel 617 and Inconel 718 alloys are reported to be susceptible for hot cracking during arc welding. Hot cracking, occurring both in the weld metal and in the heat affected zone near the fusion line (partially melted zone), is caused by segregation of certain low melting constituents at the grain boundaries. Hot cracking increases with grain coarsening and decreases with grain refinement. Many techniques have been attempted to promote grain refinement and reducing the low melting constituents during solidification.

In welding of nickel alloys, certain low melting constituents that cause hot cracking during solidification can be controlled by adjusting the composition of the weld metal such that the undesirable constituents are avoided. Hot cracking can also be controlled by appropriate choice of weld thermal cycles. In the present work, an attempt is made to study the effect of various filler metals on hot cracking during welding of the two nickel base alloys, Inconel 617 and Inconel 718. The study also attempts to study the effect of heat input on hot cracking in welding of the two nickel base alloys.

One method that has not been much attempted for controlling hot cracking in welding of nickel base alloys is introduction of vibratory treatment

during weld solidification. Though this method has been attempted to avoid hot cracking for casting applications for many metals and also for welding of certain other alloys like high strength aluminium alloys and stainless steels, it has not been used for welding of nickel base alloys. The present work attempts to find the beneficial effects of ultrasonic vibratory treatment in controlling hot cracking in welding of the two nickel base alloys, Inconel 617 and Inconel 718.

In this work, the two chosen materials, Inconel 617 and Inconel 718, are welded by Gas Tungsten Arc Welding (GTAW) under the conditions of varying heat inputs, with and without filler metals. Welding of the two materials is also done by incorporating ultrasonic vibration during solidification. Weldments are subjected to hot cracking tests and corrosion tests. Hot cracking resistance and corrosion resistance are related to the filler metals and the heat inputs. Beneficial effect of ultrasonic vibration during weld solidification is studied in terms of improvement in hot cracking resistance and corrosion resistance which in turn are related to grain refinement or dendritic fragmentation in the weld metal. The filler metal chosen for welding of Inconel 617 is ERNiCrCoMo-1. The filler metal chosen for welding of Inconel 718 is ERNiFeCr-2. 2.

Inconel 617 was welded under three filler metal conditions, namely, with filler metal ERNiCrCoMo-1, with filler metal of composition identical with base metal and without filler metal (autogenous welding). Similarly Inconel 718 was welded under three filler metal conditions, namely, with filler metal ERNiFeCr-2, with filler metal of composition identical with base metal and without filler metal (autogenous welding).

Gas Tungsten Arc Welding (GTAW) process was used for welding studies. Welding was done with a constant travel speed and constant arc voltage. Heat input was varied by varying the welding current alone. Three welding currents, namely, 80A, 100A and 120A were used. After conducting detailed characterization tests on the welded plates, certain conditions that favour control of hot cracking were identified, and for these conditions, further welded

coupons were prepared with application of ultrasonic vibration during weld solidification Houldcroft test was used to determine the hot cracking resistance of weldments.

After welding, welded specimens were subjected to dye penetrant test for proper estimation of crack length. Since the Houldcroft specimen dimensions are fixed, the crack length was directly used to represent the crack sensitivityunder a given set of conditions.

All the welded coupons were subjected to cracking test using Houldcroft test, microstructural analysis using optical microscope and SEM, hardness test and corrosion test. In Houldcroft test, crack length was directly used as an index of crack susceptibility. In microstructural analysis, dendritic arm length was measured using image analysis software. In corrosion test, using Potentiodynamic polarization test, corrosion rate was measured in mpy. Hardness test results were used for indirectly relating with the extent of grain refinement and dendritic fragmentation.

Results show that for both the base metals, namely Inconel 617 and Inconel 718, for each of the three filler metal conditions, heat input influences the hot cracking behaviour. Similarly for a given heat input, the three different filler metal conditions show varying level of hot cracking.

Results show that for a given heat input, welding with filler metal ERNiCrCoMo-1 (for Inconel 617 base metal) or ERNiFeCr-2 (for Inconel 718 base metal) results in lower crack length than either welding with filler metal of the same composition as the parent metal or welding without filler metal (autogenous welding).

Results also show that for a given filler metal condition, crack length is found to decrease with decreasing heat input. Welding with a current of 80 A results in the lowest crack length and welding with a current of 120 A results in the highest crack length for each of the three filler metal conditions for both the base metals. Lower heat input results in faster cooling rate which in turn leads to shorter dendritic arm lengths and finer grain sizes.

From the results, it is found that, welding with filler metal ERNiCrCoMo-1 is the best of all the three filler metal conditions for weldingof Inconel 617 base metal. Similarly welding with filler metal ERNiFeCr-2 is the best of all the three filler metal conditions for welding of Inconel 718 base metal. Further study with ultrasonic vibration was conducted by welding with filler metal ERNiCrCoMo-1 (for Inconel 617 base metal) or ERNiFeCr-2 (for Inconel 718 base metal) only, and not with the other two filler metal conditions. Also corrosion test was restricted to welding with filler metal ERNiCrCoMo-1 (for Inconel 617 base metal) or ERNiFeCr-2 (for Inconel 718 base metal) for both without ultrasonic vibration and with ultrasonic vibration.

Results of Houldcroft cracking test show that application of ultrasonic vibration results in steep reduction in crack length. One other important finding is that with ultrasonic vibration, crack length becomes very low even with high input levels.

Results of microstructural analysis by both optical microscopy and SEM show that ultrasonic vibration, under all heat input levels, causes dendritic fragmentation and grain refinement.

Corrosion test results show that there is steep increase in corrosion resistance of weld metals with ultrasonic vibration. For the Inconel 718 alloy, the corrosion resistance of weld metal with ultrasonic vibration is as high as about 1000 times compared to the weld metal without ultrasonic vibration.