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WELDABILITY OF NICKEL ALUMINIDES

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ABSTRACT

The weldability of nickel aluminides, in terms of resistance to hot cracking, is evaluated based on testing of thin sheet using the Sigmajig hot cracking test and simulated repair welding of 2.5 × 2.5 × 7.5 cm ingots. The thin sheet tests showed that certain alloy compositions have cracking resistance within the range of commercial type 316 stainless steel. The ingot tests showed that only a few compositions could be welded without cracking. It is hypothesized that oxygen plays a role in the operative hot cracking mechanism. Rolled and welded tubing has been produced successfully from some of these materials.

KEYWORDS

Nickel aluminides; ductile intermetallics; hot cracking; weldability testing; casting repair; alloy development; superalloys

INTRODUCTION

Intermetallic alloys based on the Ni_3Al composition have mechanical and physical properties which make them attractive candidates for numerous applications requiring high strength, and erosion and wear resistance over a wide temperature range (Liu, 1984). At temperatures up to 1000°C, strength can exceed that of many nickel-based superalloys, and strength actually increases with temperature over part of that range.

Limited weldability has restricted the use of many of the aluminide compositions, but an ongoing program at Oak Ridge National Laboratory has made considerable progress toward improved weldability through composition modification and process/procedure development.

Early work showed that the sensitivity to hot cracking is strongly affected by boron level (David et al., 1985, Santella et al., 1986). Boron is necessary for grain boundary ductility in base metal, but has an adverse effect on weld cracking above about 200 parts per million by weight. Similarly, it has been shown that small amounts of oxygen strongly reduce cracking resistance.

Weldability evaluations have been conducted on thin sheet material using the Sigmajig test, and on 2.5 × 2.5 × 7.5 cm (1 × 1 × 3 in.) cast ingots using the cold wire gas tungsten arc process. Current results will be summarized and recommendations made for optimum weldability for this important class of alloys.

EXPERIMENTAL

Over 400 specific alloy compositions of nickel aluminides have been evaluated in the overall alloy development program at Oak Ridge National Laboratory. From this large population of compositions, four have emerged as primary candidates for further development. The aim analyses for these four are shown in Table 1. Weldability results are presented for each of these generic alloys.

Table 1. Aim analyses for developmental nickel aluminides

	Composition, wt %					
Alloy	Ni	Al	Cr	Zr	Mo	B
IC-50	Balance	11.3		0.6		0.02
IC-218	Balance	8.5	7.8	0.8		0.02
IC-221	Balance	8.5	7.8	1.7		0.02
IC-396	Balance	8.0	7.8	0.8	3.0	0.01

The Sigmajig test (Goodwin, 1987) was developed at Oak Ridge National Laboratory to determine the sensitivity of thin sheet (<3 mm) material to hot cracking. The test preapplies a transverse stress, sigma (hence the name), to a 5 × 5 cm specimen, which is subsequently welded along its centerline using the autogeneous gas tungsten arc process. By iterating the preapplied stress level, a threshold cracking stress, σ_0, is determined, above which cracking is first observed for a given heat of material. This threshold cracking stress value has been found to be highly reproducible, and very sensitive to compositional variations.

By their nature, the nickel aluminides have limited weldability, due to their propensity to hot crack. Recent results, however, are encouraging, and indicate better weldability than was initially envisioned. As shown in Fig. 1, commercial austenitic stainless steels show wide heat-to-heat variations. Type 304 heats range from 241 to 345 MPa (35 to 50 ksi) threshold stress, and type 316 heats range as low as 103 MPa (15 ksi). By comparison, some of the better nickel aluminide compositions, particularly IC-50 heats, can be as high as 207 MPa (30 ksi). The chromium-bearing alloys IC-218 and IC-221 generally have lesser weldability than IC-50, and the molybdenum-bearing cast alloys (IC-306 is a direct predecessor of IC-396) are even more susceptible to hot cracking.

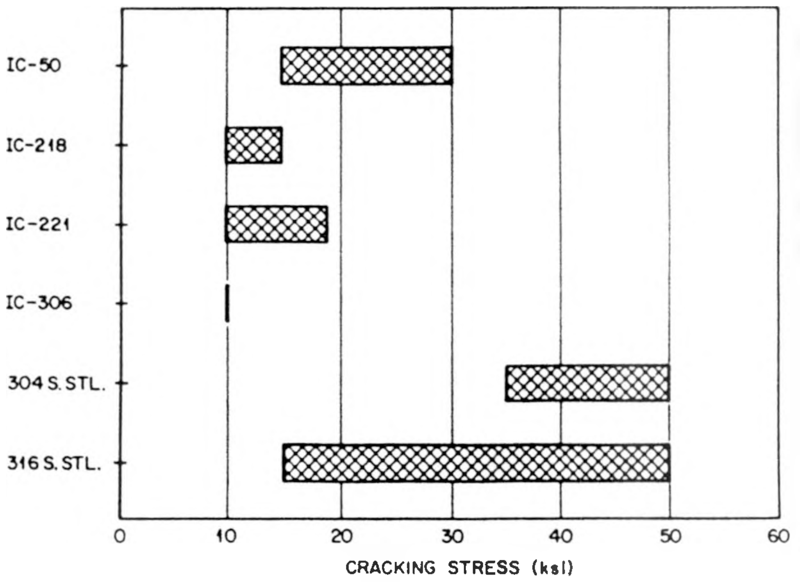

Fig. 1. Sigmajig cracking stress values.

Limited thin sheet data are available for IC-306 and IC-396 due to the difficulty in reducing ingots to sheet; the fact remains, however, that the best of the nickel aluminides can have hot-cracking resistance within the range of commercial heats of type 316 stainless steel, itself considered to be readily weldable compared with many other materials.

WELD REPAIR OF CASTINGS

We have studied weld repair of castings using the cold wire gas tungsten arc process to fill machined grooves in 2.5 × 2.5 × 7.5 cm (1 × 1 × 3 in.) ingots in IC-218, IC-221, and IC-396. As might be anticipated, arc-melted ingots have, in general, shown significantly less cracking than air-melted ingots. Although crack-free welds can readily be produced in a controlled-atmosphere chamber, and bead-on-plate autogeneous welds can be made outside the chamber, the weld groove geometry with the addition of filler wire presents a difficult problem.

A summary of current results is shown in Table 2. As noted from the table, several approaches were tried to eliminate cracking. Higher or lower than nominal zirconium or hafnium levels were investigated, as well as additions of vanadium, cerium, and yttrium. Some modifications showed improvement when welded in an atmosphere chamber, but all cracked when welded outside. Crack-free welds were obtained with reduced boron levels in both the IC-218 and IC-396 compositions. It appears, as a collective comment, that oxygen may play a major role in the operative hot-cracking mechanism in these alloys. Observations which support this hypothesis include the following:

Table 2. Summary of weldability results for arc-melted 2.5 × 2.5 × 7.5 cm nickel aluminide ingots[a]

Cracked:[b]

IC-50, IC-50 (1.7Zr), IC-50 (3.0Zr), IC-50 (3.0Hf)
IC-50 (3.4Hf), IC-50 (1V), IC-50 (3V), IC-50 (0Zr, 0.7Ce)
IC-50 (0Zr, 0.5Y)
IC-218, IC-218 (1.7Zr), IC-218 (1.7Zr, 2Ce)
IC-218 (1.7Zr, 2Ce, 0.005B), IC-218 (1.7Zr, 2Ce, 0.002B)
IC-396, IC-396 (1.7Zr), IC-396 (1.7Zr, 2Ce)
IC-396 (0.005B), IC-396 (0.5Ce), IC-396 (2Ce, 0.002B)
IC-396 (1.7Zr, 2Ce, 0.002B)

Did not crack:

IC-218 (0.002B)
IC-396 (0.002B)

[a]Composition modifications in wt %.

[b]Centerline cracking, fusion zone cracking, and/or heat-affected zone cracking when welded outside atmosphere chamber.

- Surface films on thin sheet material, mostly oxides, were found to be detrimental; electropolishing or other surface cleaning techniques improved cracking resistance.
- Using the Sigmajig test, addition of 2% oxygen to the argon shielding gas reduced the threshold cracking stress to near zero.
- During early alloy development, additions of zirconium or hafnium improved weldability. These elements should getter oxygen.
- In some cases, rare earth additions improved cracking resistance, as with zirconium and hafnium.
- In general, electroslag remelted material has shown better weldability than powder metallurgy material.
- Fine-grained material is usually more resistant to heat-affected zone cracking than coarse-grained material. Increased grain boundary area would reduce oxygen segregation at grain boundaries.
- Slow welding travel speed gives better results than higher travel speeds. In addition to reducing thermal gradients, slow travel allows more time for oxygen gettering.

CONCLUSION

Studies are continuing to develop crack-resistant modified compositions, and at the same time, much is being learned about the basic mechanisms of hot cracking in these alloys.

One indication of progress is shown in Fig. 2; roll-formed tubes of IC-50 composition have been successfully seam welded using the manual gas tungsten arc process with cold wire feed. As development proceeds, there is good reason to believe that improved weldability will allow these interesting materials to have an even broader range of potential applications.

ACKNOWLEDGMENTS

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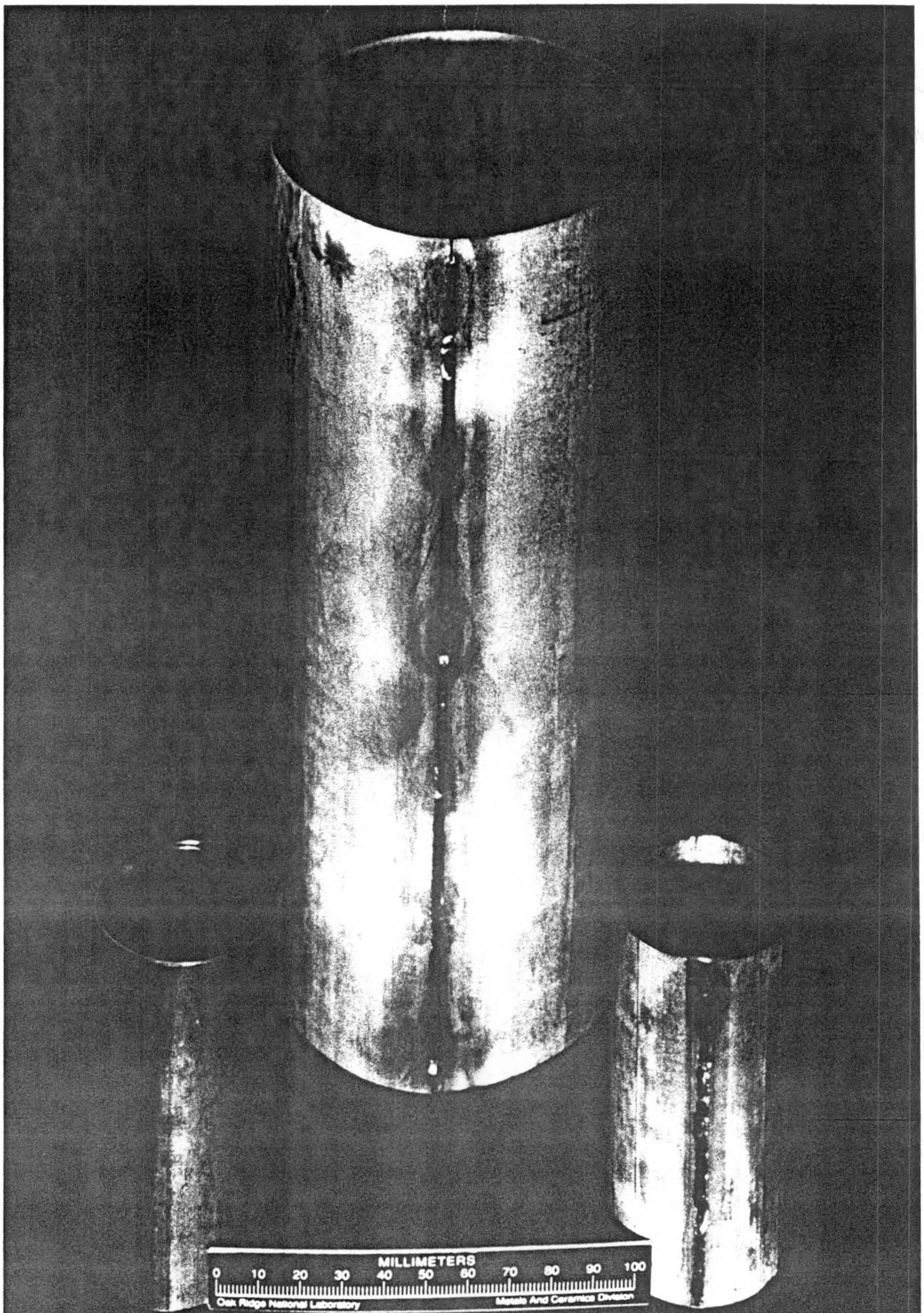

Fig. 2. Gas tungsten arc seam welded tubes of nickel aluminide.