Research, pp. 304-11, John Wiley and Sons, New York, 1961.
[14]G. Brinson and M. E. Hargreaves: *J. Inst. Metals*, 1958-1959, vol. 87, pp. 112-19.
[15]H. S. Rosenbaum: *Acta Met.*, 1961, vol. 9, pp. 742-48.
[16]H. Ll. D. Pugh: The Mechanical Properties and Deformation Characteristics of Metals and Alloys Under Pressure in *Irreversible Effects of High Pressure and Temperature on Materials*, pp. 68-137, American Society for Testing Materials, Philadelphia, Pa., 1965.

Aluminide-Ductile Binder Composite Alloys

John S. Benjamin and Nicholas J. Grant

A series of composite alloys containing a high volume of NiAl, Ni_3Al, or CoAl, bonded with 0 to 40 vol pct of a ductile metal phase, were prepared by powder blending and hot extrusion. The binder metals were of four types: pure nickel or cobalt, near saturated solid solutions of aluminum in nickel and cobalt, type 316 stainless steel, and niobium. Sound extrusions were obtained in almost all instances. Studied or measured were the following: interaction between the aluminides and the binders, room-temperature modulus of rupture values, 1500° and 1800°F stress rupture properties, hardness, structure, and oxidation resistance. Stable structures can be produced for 1800°F exposure, with interesting high-temperature strength and good high-temperature ductility. Oxidation resistance was excellent.

A large number of experimental investigations have been made of the role of structure on the properties of cermets and composite materials. Gurland,[1] Kreimer *et al.*,[2] and Gurland and Bardzil[3] have indicated the preferred particle size in carbide base cermets to be about 1 μ, with a hard phase content of 60 to 80 vol pct. The optimum ductile binder thickness was noted to be 0.3 to 0.6 μ.[1] Complete separation of the hard phase particles by the binder is important in reducing the severity of brittle fracture.[2]

The purpose of the present study was to produce structures comparable to the conventional cermets, using a series of relatively close-packed intermetallic compounds rather than carbides as the refractory hard phase, and to study the effects of binder content and composition on both high- and low-temperature properties. The selected intermetallic compounds were particularly of interest because of the potential they offered in yielding room-temperature ductility. The highly symmetrical structures are known to possess high-temperature ductility and room-temperature toughness. Based on a ductile binder, the alloys were prepared by the powder-metallurgy route to avoid melting and subsequent alloying of the matrix, and were extruded at relatively low temperatures. It was expected that the composite alloy would retain useful ductility. In contrast, infiltration and high-temperature sintering led to alloying of the matrix and to decreased ductility.

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The systems Ni-Al and Co-Al were selected for this study. In the Ni-Al system the compounds NiAl, having an ordered bcc *B*2 structure, and $Ni_3Al(\gamma')$, having an ordered fcc $L1_2$ structure, were chosen. In the system Co-Al the intermetallic compound CoAl with an ordered bcc *B*2 structure was used.

ALLOY PREPARATION

The intermetallic compounds, see Table I, were prepared by using master alloys of Ni-Al and Co-Al, with additions of either cobalt or nickel to achieve the desired compositions. The master alloy in crushed, homogenized form, was melted with pure nickel or cobalt in an inert atmosphere, cold copper crucible, nonconsumable tungsten arc furnace.

The resultant intermetallic compounds were homogenized at 2192°C in argon, crushed, and dry ball-milled in a stainless mill to −100 and −325 mesh for the Ni-Al compounds and to −325 mesh for the CoAl compound. Finer fractions were separated for some of the composite alloys.

Several ductile binders were utilized. These included Inco B nickel, 5 μ; pure cobalt, 5 μ, from Sherritt Gordon Mines, Ltd.; fine (−325 mesh) niobium hydride powder; fine (15 μ) type 316 stainless-steel powder; and near-saturated Ni-Al and Co-Al solid-solution alloys, also in fine powder form.

The niobium hydride was decomposed above about 700°C in processing of the compacts in vacuum to produce niobium powder.

The Ni-7.1 pct Al and the Co-5.3 pct Al solid-solution alloys were prepared from pure nickel or cobalt and pure aluminum by nonconsumable tungsten arc melting under an inert atmosphere. The ingots were homogenized, lathe-turned to fine chips, and dry ball-milled in air to −325 mesh powder. These solid-solution alloys are designated NiSS and CoSS; see Table I.

Subsequently the hard and ductile phases were dry ball-milled as a blend. Experiments clearly established the need to coat the hard particles with the ductile binder to optimize subsequent hot compaction by extrusion. Ordinary dry mixing usually resulted in nonhomogeneous alloys which were quite brittle.

Conventional cermets are consolidated by liquid phase sintering or infiltration, which results in undesirable and uncontrolled alloying of the binder phase. For this study, a loose (unsintered) powder-extrusion process was employed, minimizing reactions between binder and hard particle, thereby permitting much greater control of composition and structure. The constituent powders were first mixed in the desired