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2,910,356

CAST NICKEL ALLOY OF HIGH ALUMINUM CONTENT

Original Filed July 19, 1956

3 Sheets-Sheet 1

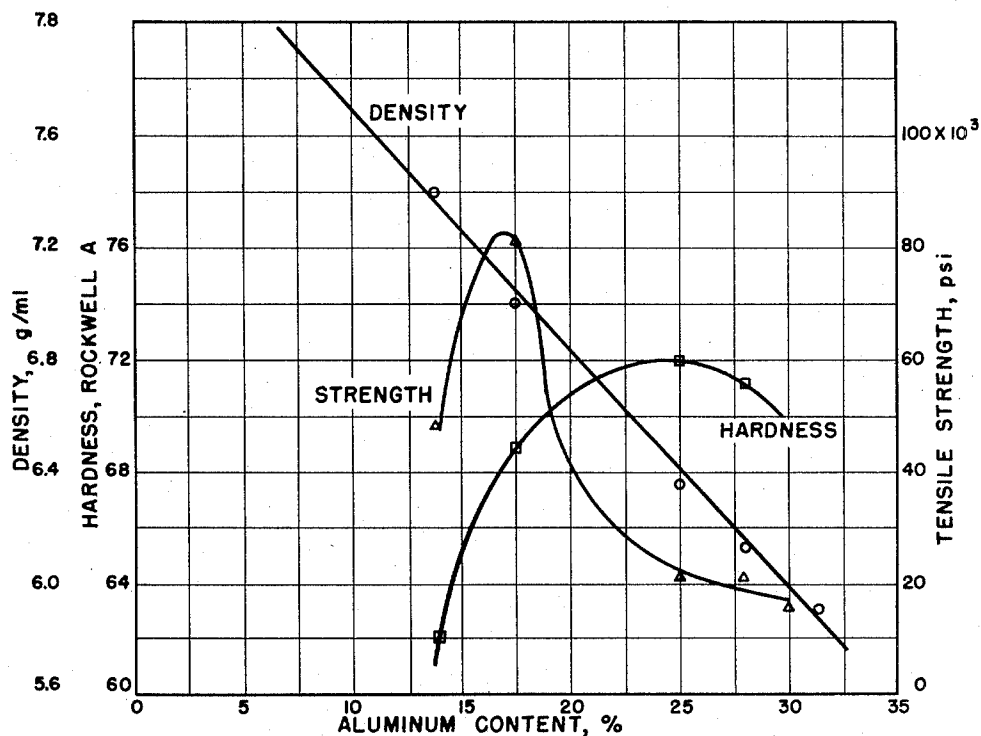


FIG. 2

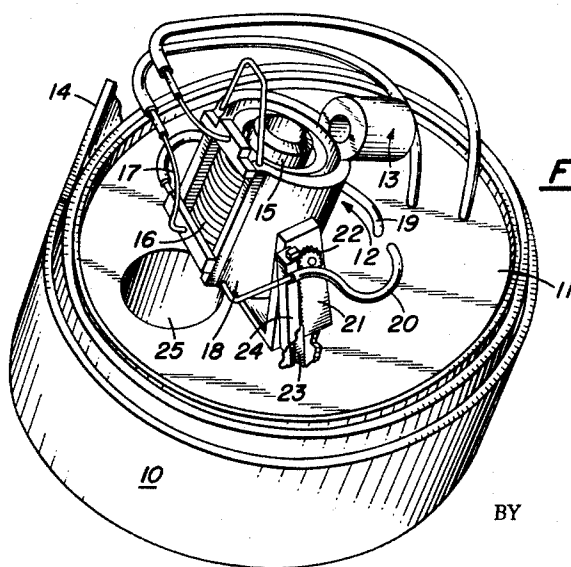


FIG. 1

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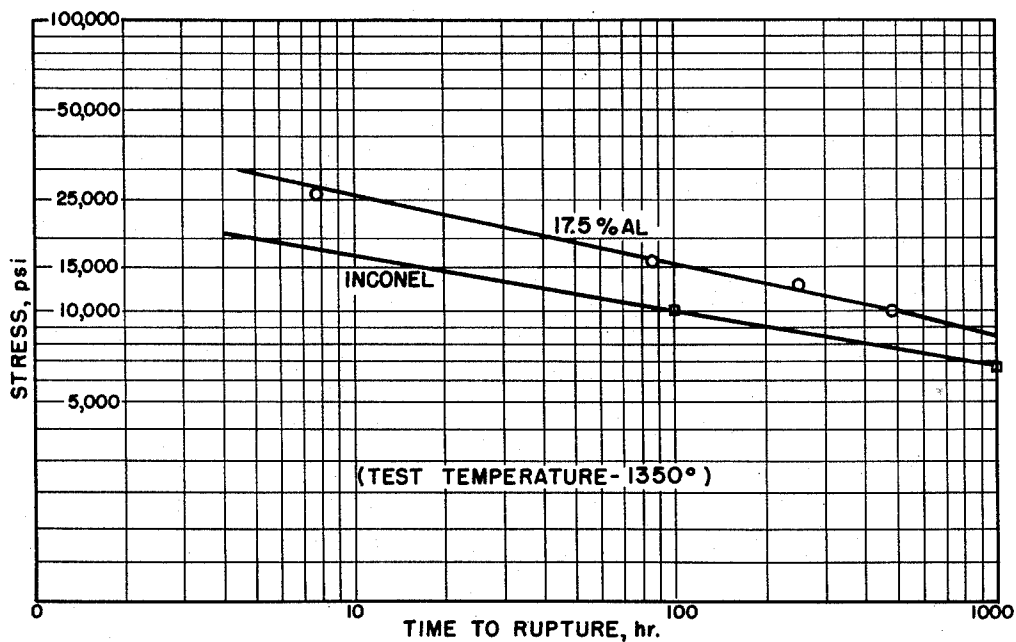
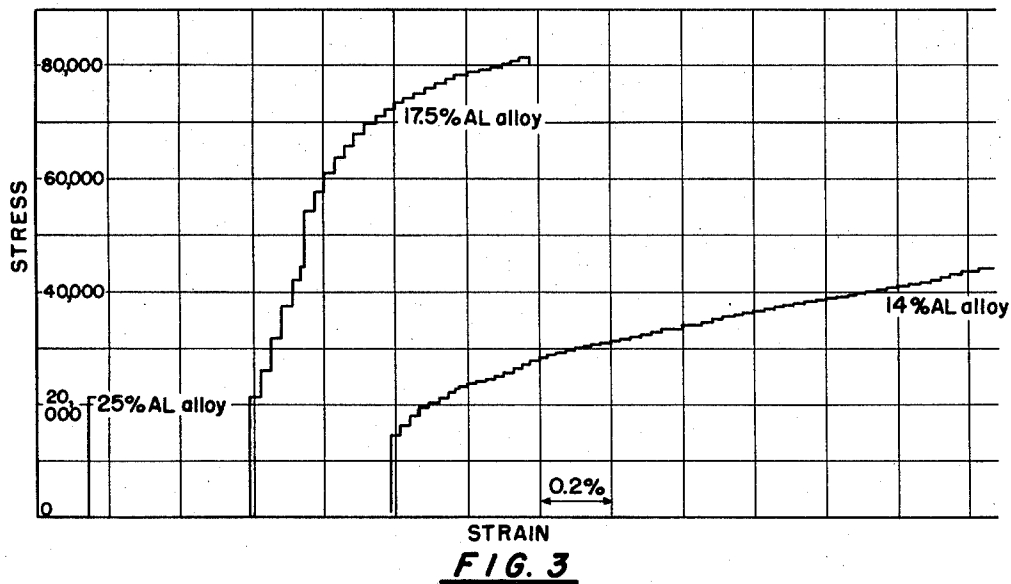


FIG. 4

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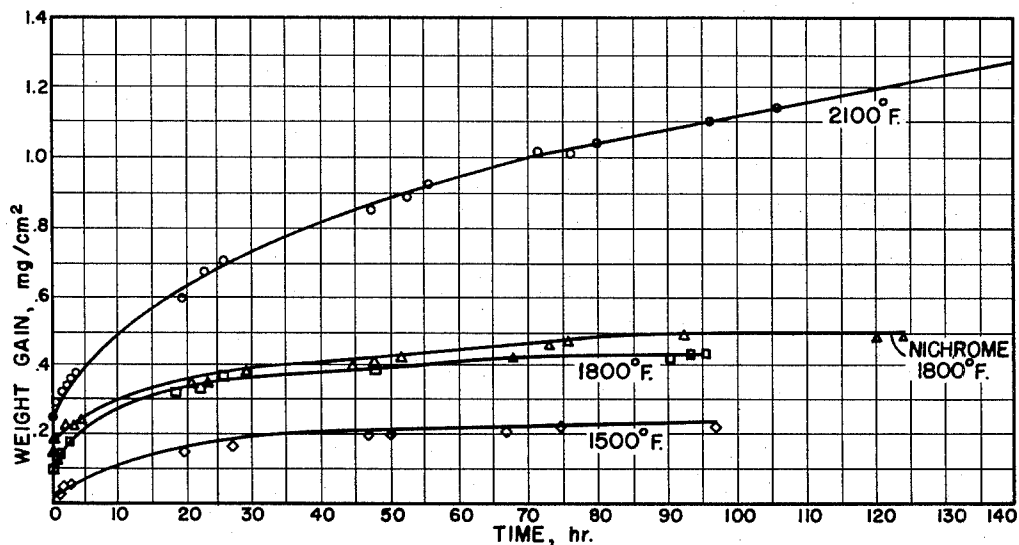


FIG. 5

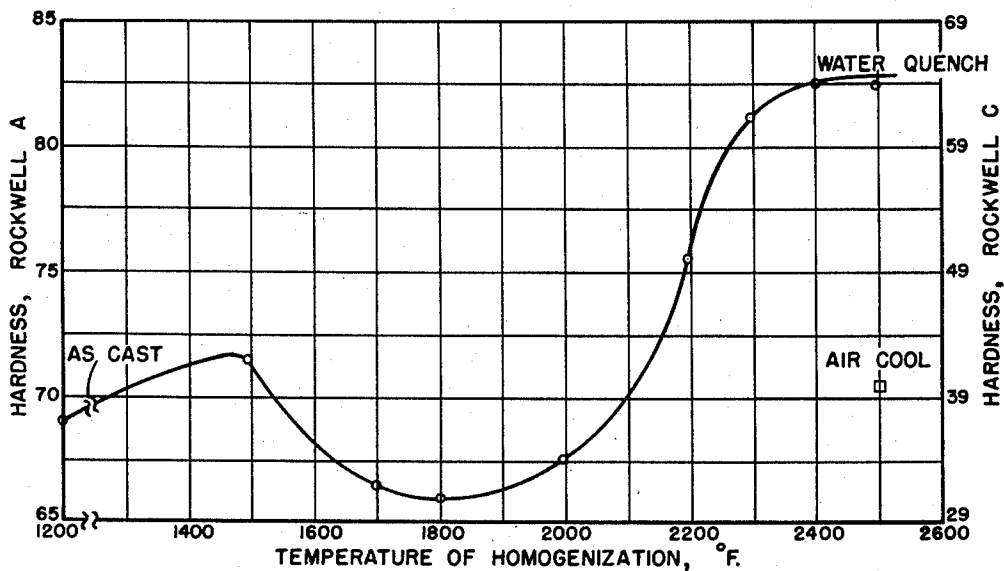


FIG. 6

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CAST NICKEL ALLOY OF HIGH ALUMINUM CONTENT

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Original application July 19, 1956, Serial No. 532,128. Divided and this application October 16, 1956, Serial No. 616,355

1 Claim. (Cl. 75—170)

(Granted under Title 35, U.S. Code (1952), sec. 266)

The invention described herein may be manufactured and used by or for the Government of the United States of America for governmental purposes without the payment of any royalties thereon or therefor.

This invention relates to cast nickel aluminum alloys in which the aluminum is present in amounts in excess of 10 percent by weight.

Intermetallic compounds, such as the nickel-aluminum compound NiAl, are known to possess properties radically different from those of their constituent elements. In the case of NiAl, for example, the melting point is high compared with that of nickel and aluminum, and there are important differences over the constituent metals in modulus-of-rupture strengths and oxidation resistance at high temperatures. The intermetallic Ni₃Al also possesses distinctive properties.

NiAl intermetallic compositions have been prepared heretofore by the methods of powder metallurgy, casting methods resulting in extremely weak, porous and fragile bodies, due primarily to the high exothermic heat developing in the mass. The present invention contemplates a casting procedure for nickel-aluminum mixtures with the aluminum in excess of 10% and, particularly, in the 14–30% range in which the exothermic temperatures are controlled by the particle size of the mixed metals, by the method of heating, and by the sequence of treatment during heating.

An outstanding object of the invention is to provide a cast nickel-aluminum composition which contains intermetallic phase alloys and which possesses high tensile strength both at room and high temperatures. Another object is to provide a cast alloy of nickel and aluminum, containing at least 10 percent aluminum, which may be hot rolled. Still another object is to provide a cast nickel-aluminum alloy containing about 14 to 30 percent aluminum which, at high temperatures, is thermal-chock resistant and hard, possesses adequate impact strength and resists oxidation.

Additional objects are to provide a nickel-aluminum alloy with at least 14 percent aluminum which serves readily as a base for additional metal alloys, and which eliminates use of fluxes in the alloy casting process.

Other objects and many of the attendant advantages of this invention will be readily appreciated as the same becomes better understood by reference to the following detailed description when considered in connection with the accompanying drawings wherein:

Fig. 1 is a perspective view of the crucible and mold unit partly tilted toward pouring position;

Fig. 2 is a set of curves showing change of hardness, density and tensile strength for different values of aluminum content of the nickel aluminum alloy;

Fig. 3 is a set of stress-strain curves showing the ductility of the nickel-aluminum alloy for different selected percentages;

Fig. 4 is a set of curves showing the stress-time-to-rupture values of the nickel-aluminum alloy as compared with Inconel;

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Fig. 5 is a set of curves indicating oxidation effects of the alloy for different temperatures and in comparison with Nichrome; and

Fig. 6 is a curve showing the variation of hardness of the nickel-aluminum alloy having 17.5 percent aluminum, with variation in the temperature of homogenization.

In the manufacture of the alloy, the castings are prepared in a bell-jar vacuum induction furnace unit, as illustrated in Fig. 1, including the support casing 10, the base plate 11, and induction furnace 12, the mold 13 and the bell-jar 14. The furnace comprises a tubular, refractory, alumina crucible 15, having an open top end for reception of the metal charge, an enclosing tubular coil 16 of an electrical conductor 17 serving to impart inductive heating flux to the metallic crucible contents, and a cooling jacket 18, provided with coolant connections 19 and 20, surrounding the coil 16. The furnace is mounted pivotally on upright stanchions 21, one of which is shown in Fig. 1. The pivot rod terminates in a pinion 22 external to stanchion 21; and a rack 23, movable in sleeve 24 by mechanism (not shown) placed in the support casing 10, serves to rotate the crucible through a limited arc of movement for discharge of the molten metal.

For convenience, and to eliminate spillage, the mold for the casting is attached to the upper edge of jacket 18, mid-point between the pivot points and on the side of the crucible which is below on pouring movement. The mold is secured detachably to the jacket so as to extend at right angles to the crucible axis, and, when the crucible is tipped, liquid in the crucible flows directly into the upper mold 13 where it is solidified by cooling to room temperature.

In order to prevent oxidation of the molten aluminum, air is withdrawn from the crucible space in bell-jar 14 through the vacuum opening 25 in the base 11 which communicates with the vacuum pump through casing 10. Also, to prevent the molten aluminum from vaporizing, a slight positive pressure of an inert gas, such as argon, is maintained within the bell-jar.

The raw materials used in the charge are electrolytic nickel (99.95% purity) and 2S aluminum (99.0+ % purity). It is desirable that the nickel be prepared, not as a powder or grain, but in the form of discrete fragments or particles and preferably in the form of small flat chips; and the aluminum is used in small fragments or pieces of 1-inch diameter bar stock. In a typical treatment the nickel chips are placed on the bottom of the crucible and the aluminum bar pieces over the nickel. When the alternating furnace current is turned on, the nickel acts as a susceptor in the induction field and raises the aluminum temperature to the melting point. The reaction between the molten aluminum and solid nickel is strongly exothermic, especially, for high-aluminum alloys, as 20 to 30 percent aluminum, and the charge becomes molten in a few seconds, where the initial charge weight is in the neighborhood of 400 to 600 grams. The melt is stirred effectively by both the chemical reaction and the induction field. About 1 minute after the start of the reaction (for the charge mentioned) the melt is poured into the mold. This is not a limiting or critical time period as the holding time may be extended, but the time should be definite and not be extended unnecessarily because of the tendency to vaporization and danger of contamination by the crucible material. The mold substance is preferably copper in order to give a chill cast effect, but a ceramic mold is feasible although producing a larger grain size in the casting.

Close control over the process during the melting and reacting of the constituent metals is obtained by control of the size of the aluminum and nickel particles in the charge, the larger the pieces, generally considered, the better the control. The dissolving of the solid nickel into

the molten aluminum retards the violence of the reaction and keeps the maximum temperature of the reaction down. In the case of powders, not only is the reaction much more violent, but the gases entrapped in the powder briquette during the cold pressing operation are involved during the reaction and produce large pores in the fused mass. Consequently, this porous mass must be ground into powder and fabricated into useful form by powder metallurgy methods.

The nickel-aluminum alloy has been described as containing 14 to 30 percent aluminum. This range is of interest since, heretofore, castings of this alloy in the specified range possessing adequate tensile strength, thermal shock and oxidation resistance and other desired properties have not been obtainable. In addition, this range includes the intermetallic phases NiAl and Ni₃Al, and tests on these substances, as made by powder metallurgy methods, show these alloys to have desirable properties. In order to ascertain the properties of the alloy, cast as described hereinabove, a series of alloys with different aluminum percentages, was examined as to hardness, tensile strength and density, and graphs showing these properties are found in Fig. 2. These graphs show a linear decrease of density with increase of aluminum; an increase in hardness up to about 25 percent aluminum, followed by a decrease; and a pronounced peak in tensile strength at an aluminum percentage of 17.5, in the alloy. On examination of the structure of this 17.5 percent alloy by X-ray techniques, it is found to correspond to the NiAl plus Ni₃Al phases of the nickel-aluminum phase system, Ni₃Al being the intermetallic phase containing approximately from 13.3 to 16 percent aluminum and NiAl being the intermetallic phase containing approximately from 24 to 36.5 percent aluminum at room temperature.

It is pointed out that the 17.5 percent aluminum alloy not only possesses marked tensile strength amounting to 79,600 pounds per square inch at room temperature, but also the hardness and density are substantial. In Figs. 3 to 6 are graphs showing other properties of the 17.5 percent aluminum alloy. Fig. 3 illustrates the stress-strain characteristic of the alloy to the rupture point, not only for the 17.5 percent aluminum alloy but also for alloys containing 14 and 25 percent aluminum, the values corresponding to the intermetallic phases NiAl and Ni₃Al, respectively. Fig. 4 illustrates the stress-to-rupture time for the 17.5 percent aluminum alloy as compared with Inconel, a refractory alloy capable of uses parallel to the described alloy. Fig. 5 shows graphs descriptive of oxidation properties of the described 17.5 percent alloy as compared to Nichrome, both at 1800° F. The oxidation gain of the 17.5 percent alloy at temperatures of 1500° F. and 2100° F. is also shown. Fig. 6 illustrates the effect of homogenization treatment on the 17.5 percent aluminum alloy for temperatures varying from 1200° F. to 2500° F. the alloy being held at selected temperatures for a number of hours, as 48 hours, bringing about elimination of as-cast heterogeneities, changes in composition of the Ni₃Al and NiAl phases and changes in the relative quantity of each phase. The phase changes are apparent from examination of photomicrographs, indicating a progressive solution of the Ni₃Al phase in the NiAl phase which becomes complete around 2400° F. Beginning around 2200° F., also, a needle-like martensite structure appears in the grains on cooling, which appears to be closely related to the increase in hardness as shown in Fig. 6.

It is noteworthy that at 2400° F. where all phases of the 17.5 percent-aluminum alloy have transformed to NiAl, the alloy could be readily hot-rolled, a reduction of 15.9 percent per pass being sustainable. Much smaller values of reduction were obtainable for this alloy at 2200° F. and 2100° F. amounting to 3.9 and 2.1 percent, respectively. The only other alloy susceptible to successful hot-rolling is the 28 percent aluminum alloy, a crack-

free reduction per pass of 3.3 percent being obtainable at 2600° F. In this hot-rolling procedure, about 3 seconds were required to remove the ingots, to be rolled, from the furnace to the rolls. Even though the cold rolls act as a quenching medium, the centers of the ingots are untransformed NiAl, as appears from microscopic examination of polished specimens of rolled material. The fact that the alloy was able to sustain an approximately 16 percent reduction indicates that the untransformed NiAl phase is plastic.

The room-temperature tensile strength of the 17.5 percent aluminum alloy rolled to 10% reduction is 73,400 pounds per square inch, and with 50 percent rolling, 86,300 pounds per square inch. It is further noted that homogenization treatment of the as-cast 17.5 percent-aluminum alloy at 2400° F. increases the tensile strength to 94,250 pounds per square inch, with no elongation. In addition, it is important to note that the tensile strength of the alloy is retained at elevated temperatures. For example, at 1500° F. the 17.5 percent aluminum alloy has a tensile strength of 52,900 pounds per square inch (p.s.i.), as cast. Homogenized for 48 hours at 2000° F., the tensile strength is increased to 55,250 p.s.i. Rolled 50 percent at 2400° F. the tensile strength becomes 50,000 p.s.i. As cast, with 0.5 percent molybdenum added, the tensile strength becomes 52,600 p.s.i. and rolled 34 percent at 2400° F., with 5.0 percent molybdenum added, the tensile strength is 55,000 p.s.i. Of interest also is the ductility of the alloy, the values of elongation in percent for the as-cast alloy at room temperature and as-cast alloy at 1500° F. being, respectively, 0.6 and 2.9 percent, the homogenized alloys (48 hours at 2000° F.) for room temperature and 1500° F. being respectively, 0 and 2.5 percent, and the hot-rolled alloys (50% and 2400° F.) for room temperature and 1500° F. being, respectively, 0 and 4.4 percent.

The nickel-aluminum alloys, containing from 14 to 30 percent aluminum and prepared as castings with or without subsequent hot working, not only possess desirable properties such as high strength, corrosion resistance and low specific gravity but also are formed of metals readily available as distinguished from the expensive alloying agents such as cobalt, chromium and niobium. Since the alloy is corrosion resistant at room temperature it may be used, for chemical equipment and dental supplies. It is, also, important to note that, if found desirable, strengthening, gain refining or deoxidizing agents may be added to the nickel-aluminum alloy, without diminishing the alloy strength, such as boron, carbon, calcium, lithium, titanium, molybdenum, the rare earths, silicon, zirconium, vanadium, niobium, tantalum and iron. For example, the tensile strength of 17.5 percent-aluminum alloy at room temperature is increased from 83,800 pounds per square inch to 88,600 pounds per square inch by the addition of 5.0 percent molybdenum, and to 92,600 pounds per square inch by the addition of 0.05 percent boron.

Special attention has been given to the 17.5 percent-aluminum alloy because of its outstanding tensile strength and hot-rolling capability. However, alloys with other aluminum percentages above 10 percent have desirable values, as indicated by the typical room temperature data in the following table.

Chemical composition, percent		Phases present	Tensile strength	Elongation	Hardness Rockwell A	Density, g./ml.
Ni	Al					
86	14	Ni ₃ Al	50,600	6.3	62	7.39
82.5	17.5	Ni ₃ Al-NiAl	83,800	0	69	6.99
75	25	NiAl	24,100	0	72	6.33
72	28	NiAl	20,000	0	71	6.12
70	30	NiAl	16,300	0	---	5.98

Obviously many modifications and variations of the

present invention are possible in the light of the above teachings. It is therefore to be understood that within the scope of the appended claim the invention may be practiced otherwise than as specifically described.

This application is a division of copending application No. 532,128, filed July 19, 1956.

What is claimed is:

A nickel-aluminum alloy casting having the combination of superior hot formability, strength, room-temperature and 1500° F. ductility, oxidation resistance and stress-to-rupture time, said casting being composed of an alloy consisting of the two phases Ni_3Al and NiAl with about 17.5 percent aluminum, said casting being produced by forming the nickel in small discrete chips, forming the aluminum in pieces each larger than each of said nickel chips, placing the nickel chips and aluminum pieces in an induction furnace in contiguous overlying layers, introducing an inert atmosphere into said furnace at a pressure in excess of atmospheric, melting said aluminum prior to melting said nickel by applying electromagnetic flux to said nickel said nickel chips thereupon dissolving into the molten aluminum and reacting therewith to form said alloy and pouring said molten alloy into a mold ex-

ternal to said furnace said mold being at a temperature below that of said furnace, an inert atmosphere at a pressure in excess of atmospheric being continuously maintained in the apparatus during melting, casting and cooling.

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