HIGH STRENGTH, CORROSION RESISTANT AUSTENITIC STAINLESS STEEL AND CONSOLIDATED ARTICLE

BACKGROUND OF THE INVENTION

1. Field of the Invention

The invention relates to a consolidated, fully dense, high yield strength, austenitic stainless steel article produced from nitrogen gas atomized prealloyed particles.

2. Description of the Prior Art

In accordance with experimental work incident to development of the invention, a model has been formulated to design austenitic stainless steels containing 25 to 28% chromium, 22% nickel, 6% manganese, 4 to 8% molybdenum, and about 0.80% nitrogen. The newly developed steels of the invention have been produced by rapid solidification powder metallurgy (P/M) with subsequent consolidation by hot isostatic pressing (HIP). The resulting chemical compositions meet the criteria of the alloy design model, predicting a fully austenitic microstructure, a yield strength of about 620 MPa, a minimum Pitting Resistance Equivalence (PRE) number of 50, a sigma solvus temperature ($T\sigma$) of less than 1232° C., a nitrogen equilibrium partial pressure at 1600° C. of about 500 kPa, and an alloy cost factor of 0.6 or less relative to UNS N10276. The results of experimental investigations of these steels compared to the predictions of the design model are presented hereinafter, in addition to evaluations of other HIP P/M processed austenitic and superaustenitic stainless steels, and nickel base corrosion resistant alloys.

Nitrogen is a strong austenite stabilizing alloying element that increases the strength and corrosion resistance of steels (Vol. III, Stainless Steels "Les Ulis Cedex A, France: European Powder Metallurgy Association," pp. 2117–2120). High nitrogen steels (HNS), and austenitic stainless HNS in particular, have recently received much attention in the technical literature. Information related to the strengthening effects of nitrogen in austenitic stainless steels, and interaction coefficients which may be useful in calculating the equilibrium nitrogen content of an austenitic stainless steel as related to nitrogen partial pressure have been presented. (M. O. Speidel, "Properties and Applications of High Nitrogen Steels," High Nitrogen Steels 88, Proceedings of the International Conference on High Nitrogen Steels, London: The Institute of Metals, 1989, pp. 92–96; Satir-Kolorz et al., Giessereiforschung, Vol. 42, No. 1, 1990, pp. 36–49; and Satir-Kolorz, et al., Z. Metallkde, Vol 82, No. 9, 1991, pp. 587–593.) Other literature discusses the effect of the alloying elements, including nitrogen, on the stability of the austenite phase in stainless steels. (Orita, et al., ISIJ International, Vol. 30, No. 8, 1990, pp. 587–593.) Corrosion resistance has been estimated using the PRE number, which is based upon the chromium, molybdenum, and nitrogen contents of an alloy. (Truman, "Effects of Composition on the Resistance to Pitting Corrosion of Stainless Steels," presented at U.K. Corrosion, 87, Brighton, England, Oct. 26–28, 1987.) Other corrosion literature indicates possible detrimental effects of the manganese content of austenitic stainless steels exceeding a threshold value, and the influence of the nickel content of austenitic stainless steels on stress corrosion cracking (SCC) resistance. (Bandy, et al., Corrosion, Vol. 39, No. 6, 1983, pp. 227–236; and Copson, "Effect of Nickel on the Resistance to Stress-Corrosion Cracking of Iron-Nickel-Chromium Alloys in Chloride Environments," 1st International Congress on Metallic Corrosion, London, Apr. 10–15, 1961, pp. 112–117.)

Powder metallurgy and hot isostatic pressing are well known practices and are described in detail in the prior art. (Eckenrod, et al., "P/M High Performance Stainless Steels for Near Net Shapes," Processing, Properties, and Applications Advances in Powder Metallurgy and Particulate Materials-1993, Vol. 4, (Princeton, N.J.: MPIF), pp. 131–140.) Briefly, controlled atmosphere or vacuum induction melting and gas atomization are used to produced rapidly solidified powder, which is subsequently consolidated to 100% density by HIP. The HIP P/M process results in a non-directional, fine grained microstructure and homogeneous chemical composition. The HIP P/M process was originally developed in the 1970's to produce high alloy tool steels and aerospace alloys with improved properties, and is now being used to produce corrosion resistant alloys. Many of the grades produced by HIP P/M are difficult to cast, forge, or machine as conventionally produced due to their high alloy content which may cause segregation during casting and hot working. The HIP P/M process eliminates segregation, allowing the fullest potential in corrosion resistance and mechanical properties to be attained based on chemical composition. HIP P/M not only may be used to make bar, slab, or tubular products similar in form to wrought materials, but near-net shapes as well. Earlier evaluations showed that HIP P/M materials meet the mechanical property and corrosion resistance requirements of conventional wrought counterparts. (Rhodes et al., "HIP P/M Stainless and Ni-Base Components for Corrosion Resistant Applications," Advanced Processing Techniques, Advances in Powder Metallurgy and Particulate Materials-1994, Vol. 7, (Princeton, N.J.: MPIF), pp. 283–298.) The nitrogen content of conventionally produced alloys is limited to the equilibrium nitrogen content which can be attained in the molten steel bath at atmospheric pressure. At atmospheric pressure, high nitrogen contents can be attained in austenitic stainless steels by increasing the alloying elements which increase the nitrogen solubility, such as manganese and chromium. Alternatively, in accordance with Sieverts Law, higher nitrogen contents can be obtained by increasing the nitrogen partial pressure over a bath of liquid steel. (Sieverts et al., Z. Phys, Chem., Abt. A 172, 1935, pp. 314–315.) Pressurized electroslag remelting (PESR) under a positive nitrogen pressure is one such production method. Other methods of increasing the nitrogen content of steels include solid state gas nitriding, or mechanical alloying of powders. (H. Byrnes, Z. Metallkd, Vol. 86, No. 3, 1995, pp. 156–163.) The inventors have determined that by gas atomization of UNS N08367 (Fe-24Ni-20Cr-6Mo), nitrogen contents substantially exceeding the predicted equilibrium value could be obtained. The melting and gas atomization, conducted in a nitrogen atmosphere at ambient pressure (100 kPa), resulted in nitrogen contents equivalent to a calculated nitrogen equilibrium pressure of about 350 kPa.

SUMMARY OF THE INVENTION

The invention comprises in one principal aspect thereof, a consolidated, fully dense, high yield strength, austenitic stainless steel and article thereof produced from nitrogen gas atomized prealloyed particles. The steel and article in one aspect of the invention, has a PRE greater than 55 and a $T\sigma$ not greater than 1232° C. The steel and article in other aspects of the invention has a maximum of 0.08% carbon, preferably equal to or less than 0.03%; 0.5 to 12.5% manganese, preferably 5.0 to 12.5%; 20 to 29% chromium, preferably 24 to 29%; 17 to 35% nickel, preferably 21 to 23%; 3 to 10% molybdenum, preferably 4 to 9%; not less than 0.7% nitrogen, preferably greater than 0.8% and more