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Development of High Performance Stainless Steel Powders

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Abstract

Advanced melting technology is now being employed in the manufacture of stainless steel powders. The new process currently includes electric arc furnace (EAF) technology in concert with Argon Oxygen Decarburization (AOD), High Performance Atomizing (HPA) and hydrogen annealing. The new high performance-processing route has allowed the more consistent production of existing products, and has allowed enhanced properties, such as improved green strength and green density. This paper will review these processing changes along with the potential new products that are being developed utilizing this technology. These include high strength stainless steels such as duplex and dual phase as well as stainless steel powders used in high temperature applications such as diesel filters and fuel cells.

Keywords : stainless steels, duplex stainless, dual phase stainless, high performance applications

1. Introduction

Stainless steel powders have been made via induction furnace technology since the 1960's. Relatively low volumes of stainless steel powders had dictated that small induction furnaces (typically 1 to 2 ton in capacity) are commonly used. The raw materials are melted in the induction furnace and atomized using high- pressure water and a V-Jet configuration. The chamber in which the powder is atomized is normally purged with nitrogen to prevent excessive oxidation of the powder. After atomizing the material is screened to the desired particle size distribution.

This method of manufacturing stainless steel powders was sufficient to meet the early demand for stainless steel powder. However, the recent growth in stainless powder metallurgy has led to the development of a high volume, high performance-processing route. A twenty-five ton electric arc furnace is used in conjunction with an argon-oxygen decarburization unit to melt and refine stainless steel to the required composition and temperature.[1] A bottom pour ladle transfers steel to the High-Performance Atomizer where it is converted into powder. Ferritic grades are then annealed in the hydrogen atmosphere, annealing furnace. Powders are then screened and premixed according to customer specifications.

2. Experimental and Results

The use of the high-performance processing route has allowed the development of some new grades of P/M stainless steel, such as dual phase stainless and duplex stainless. Oxidation resistant alloys can be produced with low carbon and nitrogen levels, improving their corrosion resistance.

Traditionally, when stainless parts producers have needed high strength and hardness, graphite has been added to a ferritic grade to promote martensite, or a more highly alloyed material, such as 17-4PH has been used. In applications that require abrasion resistance, hardness, ductility and high strength, wrought producers of stainless steel have developed a dual phase stainless steel consisting of a microstructure of martensite and ferrite.[2] The level of martensite is controlled according to a chemical balance:

$$K_m = Cr + 6 \times (Si) + 8 \times (Ti) + 4 \times (Mo) + 2 \times (Al) - 2 \times (Mn) - 4 \times (Ni) - 40\,(C + N) - 20 \times (P) - 5 \times (Cu)$$

In this equation, chromium, silicon, titanium, molybdenum, and aluminum are used to stabilize the ferrite. Manganese, nickel, carbon, nitrogen, phosphorus and copper promote formation of high temperature austenite, which transforms to martensite during cooling. By adjusting elements in real time in the AOD, a consistent value of K_m can be maintained.

Table I shows the physical properties of the aforementioned grades. All materials were compacted at 690 MPa and sintered at 1260 ^{o}C in a hydrogen atmosphere. The strength and hardness of the dual phase stainless steel exceed that of both the precipitation hardened 17-4 PH and the 410L with graphite added (410L + C). The corrosion resistance of this alloy (measured by salt spray testing) is similar to other ferritic stainless steels.

Table 1. Property comparison of high strength stainless steel.

Alloy	Apparent Hardness (HRA)	UTS (MPa)	0.20% OFFSET (MPa)	Elongation (%)
410L + C	49	633	358	4.9
Dual Phase	56	819	612	2.5
17-4 PH	53	757	627	1.4

Generally when nitrogen is introduced into stainless steels there is a concern for the formation of chromium nitrides, which may adversely affect the corrosion resistance of the alloy. However, in duplex stainless steels, the high nitrogen content promotes austenite, which has a high solubility for nitrogen and significantly reduces the formation of chromium nitrides. In this sense, the use of nitrogen in duplex stainless steels increases pitting and crevice corrosion resistance. Since nitrogen is a very effective solid-solution strengthening element, duplex stainless steels have excellent strength. However, the presence of austentite in the microstructure also allows the alloy to have good toughness and ductility.[3] The AOD allows nitrogen to be adjusted in the liquid metal, making its use advantageous for the production of duplex stainless steels. Nitrogen can also be introduced into the alloy by utilizing nitrogen in the sintering atmosphere. Table 2 shows the mechanical properties of duplex stainless steel sintered in three different atmospheres.

Table 2. Mechanical property data for various sintering atmospheres of dulpex stainless.

Sintering Atmosphere	Apparent Hardness (HRA)	UTS (MPa)	0.20% OFFSET (MPa)	Elongation (%)
100% Hydrogen	50	578	427	10.8
50% Hydrogen/50% Nitrogen	52	558	420	7.6
10% Hydrogen/90% Hydrogen	55	661	461	5.3

High temperature alloys which provide strength and oxidation resistance at elevated temperatures (300 °C to 1200 °C) will be critical in new applications such as fuel cell technology and diesel engines. These materials are generally used in the presence of combustion gases that may be generated from exhaust and pollution control equipment. The opportunities for these materials are on the rise. These components will be exposed to high temperatures and various service atmospheres such as superheated steam, hydrogen, and air. Particulate filters for capturing soot and ash from the exhaust of diesel engines are being used to meet the European environmental regulations. The ease of which shapes can be made from P/M products makes them extremely attractive for this application. Table 3 lists the chemical composition of 5 potential alloys for these applications.

Table 3. Chemistry of oxidation resistant alloys.

Type	Si (%)	Cr (%)	Ni (%)	Mo (%)	Cb (%)	W (%)	Co (%)
409Cb	0.85	10.80	0.08	0.08	0.50	---	---
430CB	0.85	18.00	0.08	0.03	1.00	---	---
310L	1.50	26.50	21.10	0.02	---	---	---
Super Ferritic	0.90	24.20	0.05	0.03	---	---	---
Hastelloy X	1.20	22.00	49.00	9.00	---	0.60	1.30

In general, as the alloy content increased (in particular nickel), the oxidation resistance increased. The super ferritic alloy, which contained 24% chromium, is especially resistant to oxidation. In the wrought industry, this grade is used in the manufacture of parts, which must resist scaling at high temperatures. This AOD processing of this alloy, which produces low carbon and nitrogen levels, improves its relative corrosion resistance and mechanical properties. The high temperature-mechanical properties of this alloy are far less than Hastelloy X.[3]

3. Summary

A new high performance processing route for the manufacture of stainless steel powders has been developed that allows for the improved properties of existing powder grades while providing opportunities to develop new grades of stainless steel powders to meet the increasing demands of the marketplace.

4. References

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