REMOVAL OF CERAMIC DEFECTS FROM A SUPERALLOY POWDER USING TRIBOELECTRIC PROCESSING

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Abstract

The high-pressure turbine is one of the most important components in aviation propulsion systems. The disks in a turbine work under the most severe conditions through which corrosive combustion gases are passed at high temperatures. Non-metal impurities in these disks, potentially introduced during processing of superalloy powders from which the disks are made, compromise their quality and generate discontinuities or defects, thereby becoming the location at which cracks or other mechanical failures can be initiated. Typically, sieving of the as-atomized superalloys through 200 mesh (75 μm) or 325 mesh (45 μm) screens is used as a way to decrease the concentration of the larger-sized ceramic particles. This paper describes fundamental studies using an alternative method - called triboelectric separation - to remove ceramic defects from superalloy powders.

A laboratory-scale apparatus, designed for fundamental investigations in the purification and processing of physical mixtures having particle diameters between 0-200 μm, was employed as the test platform. Through it were processed a series of alumina-seeded Udimet^R - U720 - superalloy powders, the products from which were analyzed by sieving and scanning electron microscopy. The removal of the seed varied from 23% at a 5 wt. % seed concentration to 49% at a 0.01 wt. % seed concentration. Simultaneously, the recovery of purified superalloy powders was constant and near 92%. Although more investigations are needed, the data suggest that triboelectric separation processing may be useful for removing defects inherent to superalloys.

Introduction

The high-pressure turbine is one of the most important components in aviation propulsion systems. The disks in a turbine work under the most severe conditions through which corrosive combustion flue gases at the highest temperatures are passed. As a consequence, the life of these disks can determine the life of the whole engine. For decades, efforts have been made to improve the lifetime, or delay the failure of, turbine disks.

One advanced technique for high-performance engines, which is now common practice by companies such as Allison/Rolls Royce, General Electric, and Pratt & Whitney, is the use of powder metallurgy turbine disks. Superalloy powders are manufactured by melting and atomizing to create nearly spherical particles having diameters between 1-300 μm. These superalloy particles are consolidated into billets by hot isostatic pressing and/or extrusion. Subsequent forging of these billets into geometric shapes gives superior quality disks having isotropic and homogeneous characteristics[1-3].

However, it has been determined that non-metal impurities can be introduced during melting and processing of the superalloy powders. These so-called "inherent impurities" or "defects" are usually in the form of ceramic particulates. The incorporation of impurities generates discontinuities or defects in the turbine disk, which are believed to be the location at which cracks or other mechanical failures are initiated.

It has been suggested that a significant increase in the lifetime of turbine disks would be possible, even under conditions more severe than currently used, if the ceramic impurities could be eliminated from the superalloy powders. Unfortunately, they are almost impossible to eliminate because alumina crucibles are used to melt the alloy, which is then flowed through zirconia nozzles during powder formation. This process can lead to small pieces of ceramic nozzle being worn or chipped off and, as a consequence, being incorporated into the powdered alloy. In relative terms, the amount of such impurity is almost negligible – at a level near one part per

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million by volume or about 50 ceramic particles per pound of superalloy. Importantly, even at this extremely low level, a deleterious effect is expected on the quality and lifetime of the formed components.

A way to decrease the concentration of the larger-sized ceramic particles is to sieve the as-atomized superalloy powder using 200 mesh (75 μm) or even 325 mesh (45 μm) screens. However, sieving eliminates not only the larger ceramic particles but also the larger superalloy particles, thereby decreasing the superalloy yield per melt. This decrease causes significant wastage and increases costs.

An alternate approach to improving the process yield while increasing superalloy purity is to apply a physical separation technique that selectively removes ceramic impurities. This paper describes one such approach that is called triboelectric separation. It has been under development at the Center for Applied Energy Research, University of Kentucky. It uses gas transport of particles and an electric field to selectively separate physically distinct particles after they have been charged in a bipolar manner. Although energy materials have been the focus of its application, the difference between ceramic defects and superalloy particles suggested that they may be able to be separated under the conditions employed within the triboelectric separation apparatus. The following sections detail the experimental procedure and the data relating to the removal of alumina impurities which had been added to the Udimet superalloy powders.

Experimental

The Udimet powder, labeled as U720, was supplied as a -140 mesh (<106 μm) cut. Commercial sintered alumina having particle size less than 3 mm was purchased from Aldrich. It was crushed using a mortar and pestle, and then sieved to -50+75 mesh (-300 μm + 212 μm). The superalloy and the sieved alumina were mixed, by weight percentage, to five different concentrations, including 5%, 1%, 0.5%, 0.1% and 0.01% alumina-in-superalloy. Although substantially greater than the expected concentration of ceramic defects in the alloy, the alumina was difficult to accurately seed into the superalloy when the concentration was less than 0.01%. Properties of the superalloy and the alumina are presented in Table I.

Table I. Properties of the superalloy and alumina powders.

Table I. Properties of the Udimet 720 and alumina.

	U720	Al_2O_3
Size (mesh)	-140	-50+75
Density (g/cc)	8.3	3.97

The alumina powder is significantly larger than the Udimet superalloy because the method chosen to delineate seed removal was mechanical sieving. In other words, subsequent to passing the mixtures through the triboelectric separator, the rejected impurities and purified superalloy were sieved, the largest alumina particles of which remained on top of the screen. Then, the weight of these impurities could be easily measured.

The mixtures were used as the feed material in a laboratory-scale triboelectric separation system. A diagram of it is presented in Figure 1. It consists of a powder feed and transport section, a parallel plate electric field zone and an exhaust/filtering outlet.

Up to 50 g of seeded superalloy is placed into a vibratory feeder located within a sealed and pressurized container. The powder is dropped from the feeder into a 10 mm diameter tube leading to a N_2 gas eductor. The eductor entrains the powder in N_2, flowing it through a 6 mm diameter transport line leading to the top of a parallel plate separation chamber. The gas-entrained powder attains a bipolar charge by particle-particle interactions during this gas transport to the chamber.

The gas entrained particles enter at the top, middle of the separation chamber. A flow of gas, void of particles, surrounds these injected particles. As they enter the electric field, established by applying a voltage between Cu electrodes placed 10 cm apart, negative particles are attracted towards and attach to the positive plate whereas positive particles are attracted toward and attach to the negative plate. At the bottom of the chamber is a filter that retains particles which have either fallen off or were not attached to the electrodes. Gas flowing through the filter is exhausted by an induced draft fan.

Subsequent to an experiment, the positive electrode was coated with a visible film of white-shaded powder whereas the negative electrode was coated with a metallic-shaded film. After turning off the high voltage supply, the deposits were removed by

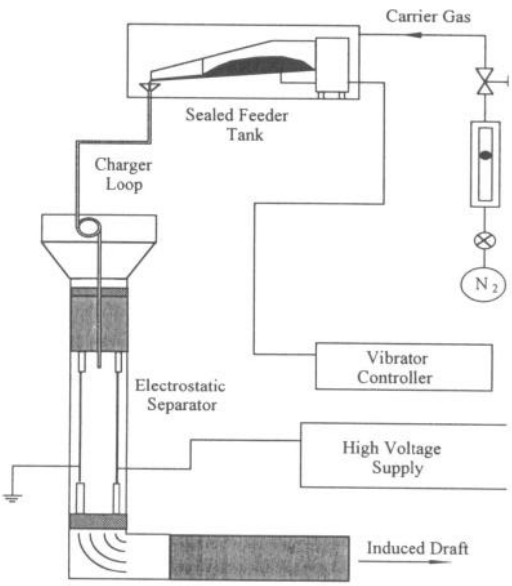

Figure 1. Laboratory triboelectrostatic separator used in pulverized coal beneficiation studies

gentle scraping and brushing into a small collection vessel. The vessels with their contents were weighed and the mass compared to the mass of seeded superalloy that was in the feeder prior to the experiment. This comparison provided mass balance information, i.e. how much of the feed could be accounted for in the products.

The negative and positive electrode products were then sieved through a 140 mesh (106 μm) screen. Because of size differences between the alumina impurities and the superalloy particles, the alumina particles were retained on the top of the sieve, while the superalloy particles passed through the sieve. The mass on top of the screen from the positive electrode product was then weighed and compared to the feed mass. This ratio provides the % alumina reduction, i.e. the % Al_2O_3 removed from the feed during triboelectric processing. The ratio of the mass from the negative electrode product relative to the mass of the feed provides the alloy recovery rate.

The dc voltage applied to the electrodes was between 15kV-to-40kV; this implies the electric field strength was 150-400 kV/m. The current to the electrodes was small, typically less than 2 mA, because a relatively small mass of sample was used during each experiment. It is believed that, during application of the triboelectric method to continuous-feed processing for superalloy cleaning, the current to the electrodes would also be small because the particles would not be collected by attachment to the electrodes. Rather, the electric field zone of the separator would be used to divert either purified superalloy or ceramic defects toward their respective collection outlets without the particles colliding with or attaching to the electrode.

Scanning electron microscopy (SEM) with energy dispersive spectroscopy (EDS) was used to determine the size distribution, morphology and particle/sample compositions. Products from both the negative and positive electrodes were examined.

Results and Discussion

The effect of voltage within the electric field cell on removing alumina from the superalloy for the 5% alumina-seeded sample is presented in Figure 2. The extent to which alumina was removed gradually increased from near 5%-to-10% as the voltage was increased from 15-to-30 kV. Then, it jumped rapidly to above 23% and was independent of voltage above 35 kV. The electric field is necessary for separating charged components from a physical mixture. Its optimal value, i.e. relative to impurity rejection efficiency, is dependent on size of the impurities to be rejected. Because the alumina seed was uniform in size, a voltage of 35 kV was used during the data acquisition for all other samples.

Table II summarizes the triboelectric separation results for the five seeded mixtures. The values in the table were the average of three or more tests. It is clear that, as the concentration of the alumina decreased, its removal rate increased from about 23% in the 5% alumina mixture to 50% in the 0.01% alumina mixture. Over this range of impurity concentrations, there was no change in the superalloy recovery rate. In all tests, about 7% of the superalloy mass reported to the electrode on which the alumina product reported, i.e. about 93% of the feed was recovered as purified superalloy.

The lowest alumina concentration used in the tests, 0.01% (wt), was equivalent to 100 ppm (wt) or 810 Al_2O_3 particle/lb of sample. At this level, the concentration of the alumina impurity is about 50 times greater than the anticipated concentration of ceramic defects inherent to some superalloys.

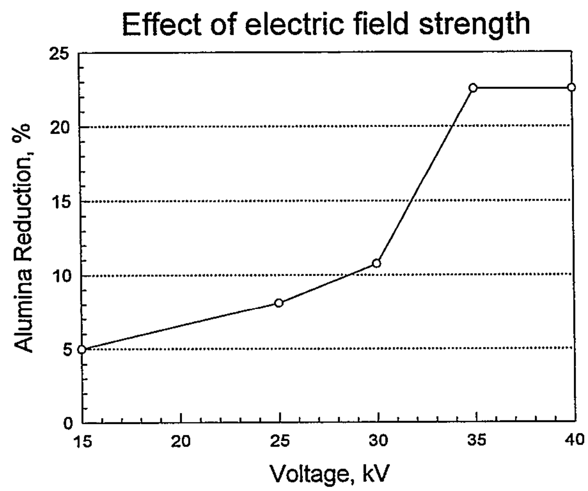

Figure 2. Alumina reduction from superalloy as the voltage on the electrodes is changed.

Table II: Summary of triboelectric separation results for alumina seeded U720 superalloy.

Feed Al_2O_3 Conc. (Wt. %)	# Al_2O_3 Particles per in^3	# Al_2O_3 Particles per lb	Al_2O_3 Removal Rate (%)	Alloy Recovery Rate (%)
5	72,500	405,000	23	93
1	14,500	81,000	31	92
0.5	7,250	40,500	36	92
0.1	1,450	8,100	43	92
0.01	145	810	49	93

However, plotting the data from Table II into Figure 3 shows that the separation efficiency was greater for samples with lower impurity concentrations. Coupled with a standard deviation analyses of the data (also presented in Figure 3) it is projected that the alumina removal rate would be nearly 70% for samples in which the impurity level would be as low as 0.0001% (1ppm or 8 Al_2O_3 particles/lb of superalloy). This concentration level is close to that anticipated for inherent ceramic defects introduced into some superalloys during atomization.

Prior to obtaining the data in Table II and Figure 3, it was anticipated that alumina seed removal from the superalloy either would become more difficult or remain constant as the seed concentration decreased. This rational was based on the fact that, in separation procession, it is generally more difficult to remove impurities from gases, liquids and solids as their concentration decreases to near trace levels.

Additionally, in our gas transport, triboelectric experimentation it had been observed that impurities in other types of powdered materials are removed at relatively constant efficiency independent of their concentration over a range of about 3%-to-15%. However, because triboelectric separation depends on establishing bipolar charge on particles with distinct surface physical properties during particle-particle collisions, and because, during gas transport to the electric field cell, the probability increases that alumina particles will collide with superalloy particles as the concentration of the alumina is decreased, it is reasonable to anticipate that the alumina particles are more efficiently and highly charged at the lower seed concentrations. Hence, it is

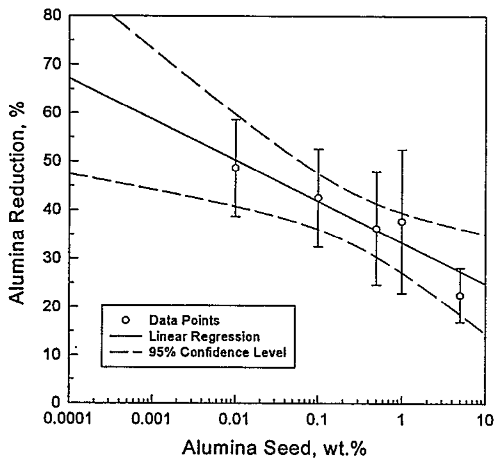

Figure 3. Alumina removal as a functional of seed concentration.

reasonable to anticipate that inherent defects, which are typically at levels near 0.0001%, would be more efficiently removed from the superalloy than is the seeded impurities.

SEM data were obtained on the products deposited on the negative and positive electrodes. These data detail morphology differences between the superalloy and the alumina impurities. The large impurity particles were absent from the negative electrode product and present in the positive electrode product. On the positive electrode were a combination of superalloy and alumina particles. These positive electrode products represent the 7% of the feed which did not report to the purified product (Table I). Also, it was evident that impurity particles were removed from the superalloy even though they were significantly larger than the superalloy particles.

Conclusions

It is possible to remove alumina particles seeded into a superalloy by use of gas transport, triboelectric separation. The removal of the impurity was dependent on its concentration; the lower the concentration, the greater was the removal. This trend suggests that the extent to which inherent defects can be removed from superalloys may be as great as 70% at defect concentration near 0.0001%, i.e.~8 particles per pound for the size of the impurities studied. Also, the results suggest that even larger sized defects are efficiently removed by triboelectric processing. More studies are necessary to understand the potential of triboelectric separation as an alternative to sieving for controlling inherent defect concentrations in superalloys.

Acknowledgments

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