HYDROCARBON ENGINEERING

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ELLIOTT® GROUP
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COVER FEATURE

FOCUS ON MATERIALS

PHILLIP DOWSON AND SIMONA WALKO, ELLIOTT GROUP, USA, DISCUSS THE DEVELOPMENT OF NEW MATERIALS FOR THE MANUFACTURE OF TURBOMACHINERY.

The development of new materials to increase performance and functionality has become a major driver of innovation in recent years, shifting the focus of research funding and increasing expenditures. In June 2011, the US Government launched the materials genome initiative (MGI) to support the efforts of US institutions, including industry and universities, to create, manufacture, and utilise innovative materials. According to MGI, it can take up to 20 years for a new material developed in a laboratory to reach the consumer market. The initiative's ultimate goal is to streamline the development and implementation of material advancements and to cut costs in the process. The European Commission for Research and Innovation also emphasises materials research as an opportunity for innovation. Dubbed the 'invisible revolution' by the European Commission, the development of new materials will be an important factor in generating solutions for the oil and gas industry in particular.

This heightened emphasis on materials research has directly affected the design and manufacture of turbomachinery, resulting in improved efficiency, performance, reliability, and longevity of centrifugal compressors and steam turbines. Over the last three years, Elliott Group has made a major capital commitment to expand and enhance the capabilities of its materials engineering and welding engineering laboratories.

Coatings

Fouling is the accretion of solids, typically polymers, on the internal surfaces of compressors and, to some extent, steam turbines. Fouling can impose significant costs on petrochemical production. In

Figure 1. Foulant build up from a compressor.

Figure 2. Compressor rotor with extensive corrosion.

Figure 3. Compressor rotor coated with Pos-E-Coat Plus.

applications such as ethylene crack gas compression, for example, fouling results from polymerisation reactions intrinsic to the compression process. The accretion of this material gradually reduces the machine's efficiency by increasing the mass of the rotor, altering its aerodynamics, and blocking flow paths. Extensive fouling can stop production or cause imbalances that can damage the machine.

Corrosion reduces a centrifugal compressor's reliability. Corrosion in a compressor is degradation of the base metal caused by a corrosive process gas or by corrosive agents introduced by a process upset (Figure 2). Corrosion damages the integrity of a compressor's components, which can require premature replacement of a part or result in failure of the machine.

In the 1970s, Elliott Group first developed amorphous nickel coatings with superior antifoulant characteristics for resistance in aggressive environments. Elliott's Pos-E-Coat® quickly became the standard coating solution for fouling issues in the oil and gas industry. The product, developed in the 1990s, provides improved antifouling and corrosion protection. It is a multilayer composite coating of modified polytetrafluoroethylene (PTFE) commonly known as Teflon (Figure 3). For hydrocarbon compression applications that require aggressive cleaning processes such as oil washing, water injection solvent or detergent cleaning, and steam purging, Pos-E-Coat 523 provides exceptional durability. It comprises a single nickel phosphorus alloy layer deposited by a chemical reaction. The product extends compressor runtime by maintaining the efficiency and reliability of the units to which it has been applied.

Seals

Abradable seals have long been used to minimise leakage between rotating and stationary elements in centrifugal compressors and steam turbines. The most frequently used abradable seals in centrifugal compressors are mica filled tetrafluoroethylene, nickel graphite, and plasma sprayed aluminum. Ongoing changes in standard operating conditions such as corrosive environments, increased moisture, and more vigorous cleaning practices have resulted in the need for tougher, more corrosion resistant seals. Elliott materials research has contributed to the development of rub tolerant, labyrinth polymer seals for these harsher operating environments. Polyetheretherketone (PEEK) and polyamideimide (PAI) are thermoplastic materials typically used as rub tolerant labyrinth seals in centrifugal compressors. Carbon fibers embedded in the PEEK matrix give these seals high strength properties. The thermoplastic matrix of the rub tolerant labyrinth polymer seals can withstand high strains to failure, and is, consequently, the only matrix that offers an intermediate modulus. The thermal properties of thermoplastics are considerably different from the thermal properties of metals. Elliott materials engineers have thoroughly tested the deflection properties of PEEK and PAI seals at various temperatures, while taking into account the effect of the tooth design on the rub tolerant characteristics of the seal.

Stress testing

The high quality base metals used to manufacture turbomachinery are carefully tested to ensure that the material's performance meets or exceeds the requirements of the specified operating conditions. Creep is a significant mechanical property when evaluating components that operate in high temperature and stress applications. Creep is the slow, time dependent deformation of a solid material under mechanical stress. Conventional, long term creep testing can extend over several years, even decades. Therefore, there is a strong interest in accelerated testing methodologies that provide quicker data acquisition.

Occasionally a customer's application requires the qualification of material outside of the standard scope of supply. Elliott materials engineers recently completed in only one month a project to ascertain the material properties, including creep data, of a 9% chromium molybdenum alloy for a steam turbine casing. After a thorough assessment of alternative test methodologies, Elliott adopted a stress relaxation test (SRT). The SRT testing method allowed Elliott to quickly obtain accurate creep data for the chromium molybdenum casing alloy with an overall testing time of one day. This project qualified the new material for steam turbine casings, and also authenticated a precise, effective method of testing for creep properties. Figure 4 shows the preparation of the chromium molybdenum alloy for the SRT test.

Non-destructive testing

There is growing interest within the hydrocarbon industry in the use of hot gas expanders for power recovery. The value of hot gas expanders is especially profound in the fluid catalytic cracking (FCC) units of refineries. Expanders in FCC service operate in high stress and high temperature conditions that are conducive to creep, as described above. Although hot gas expanders are manufactured using materials with high creep strength, creep strength progressively degrades in service exposure. Therefore, it is crucial to include creep strength analysis when conducting a remaining life assessment for these machines. Remaining life assessment is determined from material analysis based on non-destructive testing, and from machine records, including details of process upsets.

Nickel based superalloys are commonly used in the manufacture of hot gas expanders due to their excellent mechanical properties at high temperatures, particularly creep resistance. Waspaloy® is a nickel based superalloy with an austenitic microstructure that is widely applied in expander blades and disks. It has excellent age hardenability and superior strength properties through temperatures up to 1400 °F. Assessing the remaining service life of expander components, particularly rotor disks and blades, is critical. Generally, the remaining operating life of turbomachinery is difficult to assess without destructive testing or the removal of parts. Creep is a strong determining factor of remaining life, but creep measurement typically entails destructive mechanical testing.

Materials engineers perform remaining life assessment on hot gas expanders using non-destructive, indirect metal replication techniques. The metal replicas are copies of the microstructural surface of parts in service that can easily be delivered to the laboratory and analysed for defect measurements in critical areas. Waspaloy replica analyses focus on approximating the remaining life of key zones in disks and blades. Using a high magnification scanning electron microscope (SEM), materials engineers examine the replicas for growth and coalescence of precipitates, degrading mechanisms that affect creep strength (Figure 5). Microanalysis of the replicas with the SEM indicates potential accumulated creep damage that might impair the integrity of the component.

Corrosion testing in hot gas expanders

Corrosive attack is another important concern when assessing the operational life span of FCC gas expanders. As noted above, corrosion is the degradation of a material due to chemical reactions with its environment. High temperature corrosion refers to chemical attack at temperatures above 750 °F. The high temperature gaseous and catalytic environments in FCC units are prone to corrosion that can lead to blade failure at or near the blade/disk root attachment. The main factors contributing to corrosion in a hot gas expander are the gas composition, temperature, magnitude of stress, and presence of a catalyst. In a complete combustion oxidising atmosphere, a protective layer of Cr_2O_3 scale forms on the components exposed to the flue gas stream. In a partial combustion environment, the sulfidising atmosphere produces a non-protective, corrosive deposit. Spent catalyst entrapped in the blade/risk root gap can create a corrosion wedge that ruptures the blade, triggering a catastrophic failure due to the size and power of these machines.

To determine the effect of corrosion and spent catalyst on the remaining life of hot gas expander blades, Elliott's materials engineering laboratory developed a modified stress rupture test. The test apparatus consists of a temperature controlled steel

Figure 4. Materials engineer arranging a stress relaxation test specimen.

Figure 5. Materials engineer using the SEM to examine material microstructure and composition.

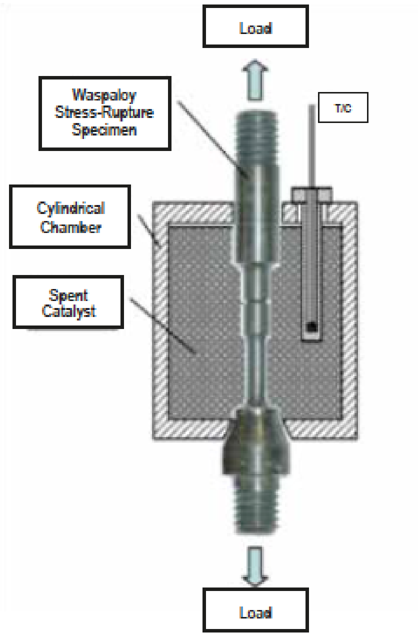

Figure 6. Diagram of the modified stress rupture test experimental apparatus.

cylinder that holds spent catalyst in close proximity to a bar of Waspaloy (Figure 6). Data from these modified stress rupture tests enable the materials engineers to calculate the remaining life of expander components made of Waspaloy. The test has also led to additional innovations related to high temperature corrosion resistance, including chromide and plasma spray coatings, steam barriers, and a new superalloy, RK1000. Developed in Elliott's Sodegaura, Japan research facility, RK1000 exhibits the same mechanical properties as Waspaloy, but with four times the corrosion resistance. RK1000 has been used in several of Elliott's TH expanders with excellent results.

Advances in welding technology

Welding is critical for the manufacturer, repair, and modification of turbomachinery. Elliott's welding engineering laboratory has produced many of the innovations in welding technology that are commonly used today. Elliott was the first compressor manufacturer to weld compressor casings beginning in the 1970s. Elliott was also the first in the industry to braze compressor impellers and to refurbish turbine and compressor rotors and shafts using the submerged arc welding process. The company has since applied gas tungsten arc welding (GTAW) to rotor restoration. After developing a method to plasma arc weld Stellite® onto the leading edge of steam turbine blades for liquid droplet erosion resistance, welding engineers have introduced methods of plasma arc welding of high alloy overlays to hot gas expander components and compressor impellers. Engineers in Jeannette, Pennsylvania and Sodegaura, Japan are currently exploring new techniques for extending the laser weld process, including laser welding of Stellite.

Conclusion

Elliott's materials engineering and welding engineering laboratories remain focused on the future of materials, welding processes, and their applications. The researchers are working to evaluate the use of lighter weight, higher strength materials in the manufacture and modification of turbomachinery, such as low density titanium alloys to reduce stresses produced in rotating components. Lightweight, high strength carbon fiber composites suggest another promising field of investigation.

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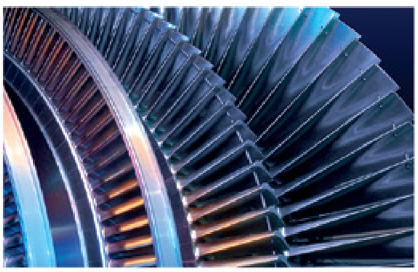

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