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Superalloys Applications

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Aerospace

The superalloys are used widely for the combustor and turbine sections of the aeroengine. This is because the operating conditions, particularly the temperature and corrosive environment, are the most extreme at these locations.

Typical components include turbine blading, nozzle guide vanes, turbine discs, combustor cans and support casings. The nozzle guide vanes direct the hot gases onto the turbine blades, which are attached to a turbine disc. The function of the blade/disc assemblies is to drive an external shaft, which is used to generate electricity (in the case of a land-based turbine), a fan or compressor (for an aircraft engine) or a propeller (in the case of a ship). Use is made of them also in the combustor chamber in which the compressed air is mixed with the fuel and the mixture ignited before being fed to the turbine. Ceramic coatings are used to restrict the temperature experienced by the superalloys, particularly in the combustor and for the turbine blading and NGVs.

Components are manufactured either in cast (e.g. turbine blading) or wrought (e.g. turbine discs, combustor cans) form - but processes such as machining and welding are usually used for finishing purposes. The development of the superalloys for these applications has contributed greatly to the fuel economy and thrust/weight ratio of these engines. This can be judged by a consideration of the turbine entry temperature (TET), defined as the temperature of the hot gases entering the turbine arrangement - the performance of the engine is greatly improved if the TET temperature can be raised. The TET of a modern aeroengine is now beyond 1500^{o}C - higher than the melting temperature of most grades of superalloy - and is about 700^{o}C greater than that of the first gas turbine engines manufactured in the 1940's. Thus the superalloys have contributed greatly to the success of the modern jet engine industry, and they continue to do so.

The nickel superalloys are not used in all parts of the jet engine. The weight of an aircraft engine must be minimized in order to reduce the cost of fuel, e.g. for transatlantic flights. The temperatures experienced by the fan and compressor sections are below about 600 deg C; consequently titanium alloys are preferred on account of their density, which is about half that of a typical superalloy (about 4 versus 8.5 g/cm3 for a typical superalloy).

Land-Based Turbines

The superalloys find application in land-based industrial-gas turbines (IGTs) which are used for electricity generation. Such combustion turbines can be broadly classified into two types: (i) aeroderivatives, which means that they are essentially aircraft engines operating as gas producers which then drive a power turbine, and (ii) heavy-duty `Frame-type'. Each type has its benefits. The aeroderivatives are typically lighter for a given power output: as a consequence the start-up time is shorter; the engines are also usually more easily maintained. They are usually in the 10 to 40 MW range, and are therefore used for back-up purposes. Frame engines on the other hand can be very large; recent engines are rated at 280 MW and larger ones are being built - these are suitable for base-load units. A relatively recent development is combined-cycle plant in which an IGT is used in combination with a steam turbine - the thermal efficiency can then approach 60%.

The superalloys are used widely for these engines, for components in the combustor and turbine sections. There is considerable incentive to make the rotor inlet temperature as high as possible, because this increases the efficiency with which electricity can be generated. This situation has provided the technological incentive for the invention of new types of superalloy for the components for these so-called industrial gas turbines or IGTs.

Cobalt-based superalloys are sometimes chosen over the nickel-based superalloys for these applications. The fuel used for IGTs often contains impurities, e.g. sulphur, which cause accelerated oxidation and corrosion of the nickel-base superalloys.

As with any electricity generating system, the lifetime is an important issue. The time between planned outages has historically been about three years or 25,000 hours - but in some instances this has been increased to five years or 40,000 hours as the components have become more reliable. The required plant lifetime as a whole is typically 30 years or 250,000 hours, but life-extension programs can push this out further. These circumstances place considerable emphasis on ensuring the integrity of superalloy components used for these applications.

Other Applications

The superalloys are also used widely for applications other than aircraft gas turbines and electricity power plant. Some of these include (i) exhaust valves, hot plugs and valve inserts in reciprocating engines (ii) hot-working tools and dies for metal processing (iii) trays, fixtures, fans and furnace mufflers for heat-treating equipment (iv) reaction vessels, piping and pumps in the chemical and petrochemical industries (v) scrubbers, flue gas desulphurisation equipment in pollution control apparatus (vi) heat exchangers, reheaters and piping in coal gasification and liquefaction systems (vii) tubing, bleaching circuit equipment in pulp & paper mills (viii) certain automotive components such as turbochargers and exhaust valves (ix) medical components, e.g. dentistry and prostheses and (x) rocket engine, e.g. for the Space Shuttle main engine.

There is also a need for advanced superalloys for use in super-critical steam-generating electricity plant as operating temperatures are moving beyond those at which ferritic steels can cope. Superalloys for other niche applications are being developed - for example for valves for diesel engines and for interconnects for high temperature fuel cells.