N18, Powder Metallurgy Superalloy for Disks: Development and Applications

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The preliminary industrial development of a powder metallurgy (PM) superalloy, designated N18, for disk applications has been completed. This alloy exhibits good overall mechanical properties after appropriate processing of the material. These properties have been measured on both isothermally forged and extruded billets, as well as on specimens cut from actual parts. The temperature capability of the alloy is about 700 °C for long-term applications and approximately 750 °C for short-term use because of microstructural instability. Further improvements in creep and crack propagation properties, without significant reduction in tensile strength, are possible through appropriate thermomechanical processing, which results in a large controlled grain size. Spin pit tests on subscale disks have confirmed that the N18 alloy has a higher resistance than PM Astroloy and is therefore an excellent alloy for modern turbine disk applications.

Keywords
microstructure, gamma prime; microstructure, grain size; microstructure, inclusions; overaging; powder metallurgy; spin tests; superalloy; turbine disks

1. Introduction

A PROGRAM on disk superalloys was initiated by SNECMA in 1984 to develop a new high-strength material for use in compressor and turbine disks for modern aeroengines. [1] The required specifications for mechanical properties were a high yield strength up to 750 °C and high creep resistance associated with a very good damage tolerance capability up to 650 °C for long-term use and up to 700 °C for limited use. The outcome of this research program was a new patented PM superalloy, N18, containing 55% γ' strengthening precipitates and exhibiting a high γ' solvus, i.e., 1190 °C. [2] The objective of the initial development phase was to optimize the industrial processing of the alloy, [3] in terms of powder production and consolidation and microstructural optimization through adequate thermomechanical treatments. It was also desired to mechanically characterize the alloy at an intermediate scale on 170-mm outer diameter isothermally forged pancakes.

An industrial-scale evaluation of the N18 alloy has been completed to confirm the excellent results of the first phase:

- Manufacturing of full-scale turbine disks according to the optimized route, detailed microstructural and mechanical characterizations on laboratory test specimens
- Exploration of temperature capability regarding thermal stability and possible improvement of high-temperature mechanical strength through microstructural modifications

2. Full-Scale Turbine Disk Characterization

2.1 Manufacturing

The 480-mm outer diameter full-scale turbine disks (average thickness 60 to 120 mm) were isothermally forged at 1120 °C from 200-mesh powder (–75 μm) 230-mm diameter extruded billets. Cleanliness control, achieved by water elutriation, revealed an acceptable ceramic inclusion rate (20 per kg within the 65 to 75 μm range). The disks were finally heat treated as follows:

- 1165 °C, 4 h solutioning + delayed oil quenching
- 700 °C, 24 h air cooling + 800 °C, 4 h air cooling (aging treatments)

2.2 Microstructural Investigations

A homogeneous microstructure was observed in the inner zone of the disk (7 to 10 μm) (Fig. 1), whereas slightly coarser grains were observed in the external zones (10 to 15 μm). The size of the secondary γ' varies from 0.15 to 0.30 μm; the smaller sizes are found in the outer part of the disk.

Cooling rates after solutioning treatment were measured by thermocouples located at the bottom of holes drilled in different areas of the disk, and the results are quite consistent with microstructural investigations. The coarser sizes (0.30 μm) are associated with lower cooling rates (65 °C/min), whereas the finer sizes (0.20 μm) can be correlated to the highest cooling rates (170 °C/min). A diagram plotting γ' size versus quenching rate (up to 1000 °C/min) has been drawn [4] and compared to two other PM superalloys (Fig. 2). A nearly constant slope is observed for all materials, which indicates a similar sensitivity.
2.3 Mechanical Characterization

Numerous specimens were cut from several disks to perform laboratory tests for mechanical properties such as tensile, creep, low-cycle fatigue (LCF), and crack propagation, data which are mandatory for design purposes.\[5\]

2.3.1 Tensile Properties

The ultimate tensile strength remains quite high (>1500 MPa) up to 550 °C and then decreases down to 500 MPa at 900 °C. Similarly, the yield strength is almost constant, about 1050 MPa up to 700 °C, and then decreases to 450 MPa at 900 °C (Fig. 3).

A correlation was established between quenching rate (and, consequently, the secondary γ' size) and the monotonic mechanical properties: Between 65 and 170 °C/min, corresponding to the γ' size evolution from 0.30 to 0.20 μm, a limited increase in both yield and ultimate stress (about 10%) was recorded for N18 (Fig. 4). Such tendencies are commonly observed in superalloys.\[6\]

2.3.2 Creep

Good creep resistance, which was a requirement of the alloy specifications, was confirmed at 650, 700, and 750 °C (Fig. 5). A comparison with reference alloys, such as INCO 718 and Astroloy, clearly shows the advantage of N18 (Fig. 6). It should also be noted that the stress-rupture elongation was close to 10% for the above-mentioned temperatures.

2.3.3 Low-Cycle Fatigue

In modern turboengines, service life is generally limited by cyclic damage associated with high loading amplitude variations at low frequencies due to operating conditions. Therefore, the low-cycle fatigue resistance of N18 was characterized in the temperature range 200 to 650 °C by numerous strain-controlled LCF tests (about 300). Cylindrical specimens (10 mm in