

Aeronautical requirements for Inconel 718 alloy

C F Elefterie^{1*}, C Guragata¹, D Bran¹, B Ghiban¹

¹ University Politehnica of Bucharest, Splaiul Independenței no. 313, district 6, Bucharest, Romania

*E-mail: elefterie_florina@yahoo.com

Abstract. The project goal is to present the requirements imposed by aviation components made from super alloys based on Nickel. A significant portion of fasteners, locking lugs, blade retainers and inserts are manufactured from Alloy 718.

The thesis describes environmental factors (corrosion), conditions of external aggression (salt air, intense heat, heavy industrial pollution, high condensation, high pressure), mechanical characteristics (tensile strength, yield strength, and fatigue resistance) and loadings (tensions, compression loads) that must be satisfied simultaneously by Ni-based super alloy, compared to other classes of aviation alloys (as egg, Titanium alloys, Aluminum alloys).

For this alloy the requirements are strength, durability, damage tolerance, fail safety and so on. The corrosion can be an issue, but the fatigue under high-magnitude cyclic tensile loading it's what limits the lifetime of the airframe.

Also, the excellent malleability and weldability characteristics of the 718 system make the material physical properties tolerant of manufacturing processes. These characteristics additionally continue to provide new opportunities for advanced manufacturing methods.

1. Introduction

In the recent time the use of the Alloy 718 increased both from economical and technical point of view. Subsequently it becomes the most widely used superalloy for aerospace applications. With applications in critical rotating parts, supporting structure, airfoils and pressure vessels within an aircraft engine, makes it the most used alloy.

Improving the Alloy 718's quality and cost are the goals of all manufacturers, while personalize the requirements for melting, forging, heat treatment process, forging and keep the balance for creep and crack growth behaviour.

The intermetallic phases known to precipitate in Inconel718 are the metastable γ' and γ'' and the δ equilibrium phase. Current applications are limited due to the metastability of the γ'' strengthening system. The efforts to increase the temperature stability of Alloy 718 with the normal approaches are not successful. In spite of wide ranges of applications, the number of investigations is limited for the mechanisms associated with tensile and cyclic deformation behaviour for this particular alloy.

In this paper, are reported the conditions designed to give the optimum properties for this alloy. The substructural changes published in the literature in Inconel 718 under cycling loading and monotonic condition are characterized and compared with other important alloys for having a better view of the importance of Inconel 718.

This subject is a matter of interest for other researchers in material science. Robert E. Schafrik, Douglas D. Ward and Jon R. Groh who studied the past, present and future applicability of the Inconel 718 and during 35 years discovered that the evolution of this alloy was a success and they believe that will be interesting to look back in another 35 years more to see the evolution of 718 alloy that set its bar high.^[3]



Sreeramesh Kalh, K. Bhanu Sankara Rao, Gary R. Halford and Michael A. McGaw^[4] explained the deformation and damage mechanisms in Inconel 718 tested under monotonic tensile strains and fully-reversed fatigue.^[4]

2. Environmental factors

Many variables influence the performance of a specific material in a specific environment. These include concentration, temperature, aeration, liquid or gaseous flow rates, impurities, abrasives, and cycling process conditions.

The atmospheric factors (e.g. relative humidity, temperature, sulfur dioxide content, hydrogen sulfide content, chloride content, amount of rainfall, dust) and even orientation of the exposed metal, all can effect marked influences in corrosion behavior. In an arid atmosphere, free of contaminants, only negligible corrosion would be expected.

Due to the presence of chromium and aluminum and formation of their respective stable oxides, the passivation of Inconel 718 surfaces is achieved, conferring its characteristic corrosion resistance.

Metals that form passive layers are susceptible to localized corrosion (pitting), which consists in the formation of short extension and deep cavities. This kind of corrosion initiates due to the break of passivation film, usually in defects such as inclusions, dislocations, grain boundaries or other interfaces.

Corrosion problems can be found in many forms. Metallic corrosion under aqueous conditions can take place by many mechanisms with quite varied results.

3. Experimental procedures

3.1. Materials and process parameters

The Inconel 718 will be heat treated according to the AMS2750 requirement with the follow parameters:

- solution annealed - 980°C – 60-80 minutes soaking time, followed by polymer quench;
- precipitation hardened - 720°C – 8 hours soaking time, cooled down to 620°C – 8 hours.

After this step will be finished, the desire of this experiment is to change the parameters, as for example the quench used, temperature, etc.

By changing the parameters slowly and compare, it will provide us important information regarding the behavior of this alloy and its mechanical properties changes.

The working process will be strictly observed knowing that for excellent stress and creeping resistance, the application temperature should be kept lower than 700°C as gamma double prime is meta stable. Beyond this limit in a prolonged use it quickly ages.

3.2. Characterization methods of mechanical properties testing

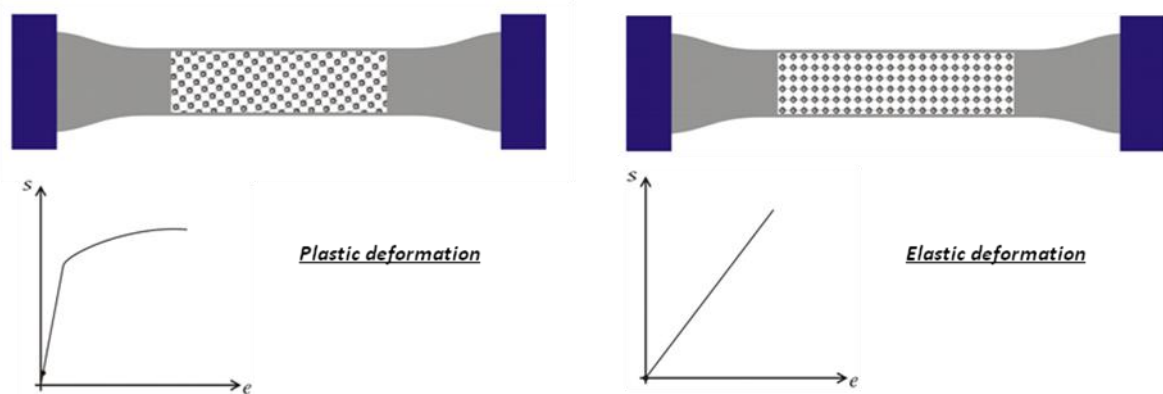
The mechanical properties of the Inconel 718 samples will be investigated first by the following methods: Tensile and Fatigue tests.

- Tensile testing

<i>The properties that are usually determined during a tensile testing are the following:</i>		
Name of determined property	Unit	Symbol
Ultimate Tensile Strength	MPa	UTS/ R _m
Yield Strength	MPa	YS/ R _{p0.2}
Elongation (Calculated)	%	A
Reduction of Area	%	Z/ RA

The UTS is usually determined by performing a tensile test and recording the engineering stress versus strain. The highest point of the stress–strain curve is the UTS. It is an intensive property; therefore its value does not depend on the size of the test specimen. However, it is dependent on other factors, such as the preparation of the specimen, the presence of surface defects, and the temperature of the test environment and material.

The Yield Strength is the material property defined as the stress at which a material begins to deform plastically. Prior to the yield point the material will deform elastically and will return to its original shape when the applied stress is removed.



The reduction of area and the elongation are reported as additional information on the deformational characteristics of the material. The two are used as indicators of ductility.

Test process

The test process involves placing the test specimen in the testing machine and slowly extending it until it fractures. During this process, the elongation of the gauge section is recorded against the applied force. The data is processed so that the result is not dependent on the geometry of the test sample. The elongation measurement is used to calculate the engineering strain, ϵ , using the following equation:

$$\epsilon = \frac{\Delta L}{L_0} = \frac{L - L_0}{L_0}$$

Where ΔL is the change in gauge length, L_0 is the initial gauge length, and L is the final length. The force measurement is used to calculate the engineering stress, σ , using the following equation:

$$\sigma = \frac{F_n}{A}$$

Where F is the tensile force and A is the nominal cross-section of the specimen. The machine does these calculations as the force increases, so that the data points can be graphed into a stress–strain curve.

The most common testing machine used in tensile testing is the universal testing machine. This type of machine has two crossheads; one is adjusted for the length of the specimen and the other is driven to apply tension to the test specimen. There are two types: hydraulic powered and electromagnetically powered machines.

- Fatigue test

In materials science, fatigue is the weakening of a material caused by repeatedly applied loads. It is the progressive and localised structural damage that occurs when a material is subjected to cyclic loading. The nominal maximum stress values that cause such damage *may be much less* than the strength of the material typically quoted **as the ultimate tensile stress limit**.

Fatigue strength is determined by applying different levels of cyclic stress to individual test specimens and measuring the number of cycles to failure. Standard laboratory test use various methods for applying the cyclic load, e.g. rotating bend, cantilever bend, axial push-pull and torsion.

The data are plotted in the form of a stress-number of cycles to **failure (S-N) curve**. S-N test data are usually displayed on a log-log plot, with the actual S-N line representing the mean of the data from several tests.

As a rough guide, the fatigue limit is usually **about 40% of the tensile strength**. In principle, components designed so that the applied stresses do not exceed this level should not fail in service. The difficulty is a localized stress concentration may be present or introduced during service which leads to initiation, despite the design stress being normally below the 'safe' limit.

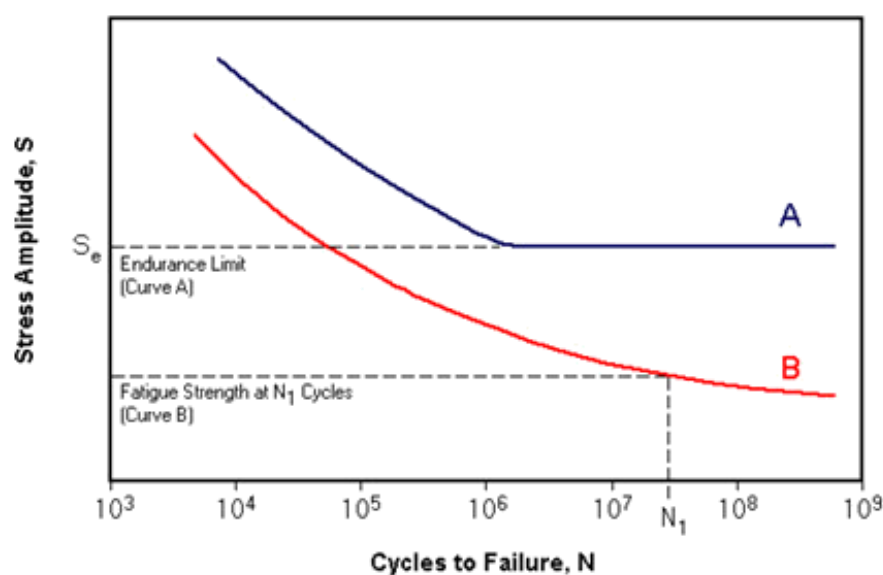


Fig.1 – fatigue limit^[9]

Most materials, however, exhibit a **continually falling curve** as in (b) and the usual indicator of fatigue strength is to quote the stress below which failure will not be expected in less than a given number of cycles which is referred to as the endurance limit.

4. Results expected

4.1. Macrostructure and Microstructure

The macrostructure of Inconel 718 needs to be without defect, no abnormal grain growth and with the macro grain size homogeneous through thickness. No evidence of non-concentric tree rings, freckles or white spots observed.

The samples will be compared with the requirements of EN2950 or ASTM E340.

The microstructure needs to consists with a fine equiaxed grain structure with grain size below the requirements of ASTM E112 – G=5 and ALA – G=3.

Twin boundaries, fine grain boundary and intergranular precipitation should be observed.

Also on the microstructure, no laves phase have to be seen.

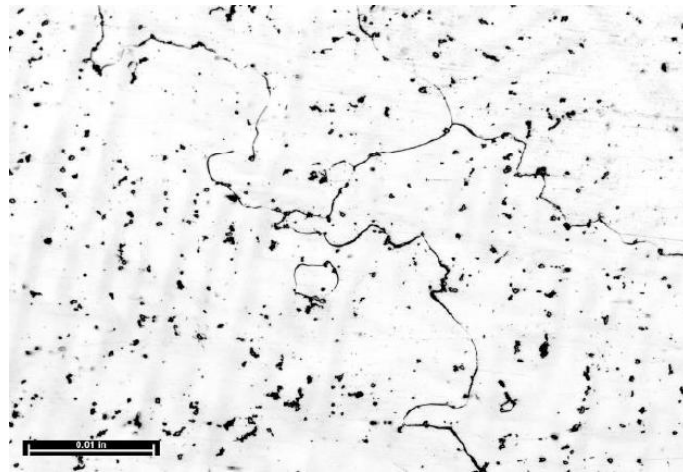


Fig.2 example of Inconel 718 microstructure from 100x^[8]

4.2. Tensile test

Tensile test will be performed for room temperature and elevated temperature (<650°C).

The expectations of the tensile test results are to be well above the minimum values of the ASTM E 10 requirement.

For room temperature			
UTS (MPa)	YS _{0.2} (MPa)	A%	Z%
1350 ≤ UTS ≤ 1550	≥ 1100	≥ 12	≥ 15
		≥ 8	≥ 12

For elevated temperature <650°C			
UTS (MPa)	YS _{0.2} (MPa)	A%	Z%
≥ 1000	≥ 860	≥ 12	≥ 15
		≥ 8	≥ 12

The behaviour of all the test sample results will be preferred as representative of the whole population. Having the results in the middle of the cloud it will be unlikely to lead to any production problems.

4.3. Fatigue test

Fatigue test will be performed at room temperature and represented thru a Wöhler regression curve.

It will be applied a strain range of 2% during fatigue and increase until the damage of the material.

5. Conclusions

An affordable Alloy 718 derivative with greater temperature capability is a long-standing desire.

This study looks to revisit the potential for an Alloy 718 derivative that would have processing characteristics similar to 718.

The new alloy is targeted to have the malleability and fusion weldability characteristics of Alloy 718, with stability at higher temperature range.

As we look to the future, the versatility of Alloy 718 ensures its continued usage, albeit for a smaller portion of future engine components due to increasing engine operating temperatures. Finding a suitable higher temperature counterpart to Alloy 718 has proven to be a daunting task.

The substructural changes in Inconel 718 will be characterized and compared with those published in the literature.

6. References

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