Development of an experimental setup for testing the properties of γ / γ' superalloys

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Abstract. Certification tests on turboshaft engines for helicopters can expose components as high pressure turbine blades to very high temperature during short time periods. To simulate these complex temperature and mechanical stress loadings and to study dimensional and microstructural stability under severe testing conditions, an experimental set-up has been recently developed. In this paper, we first present this new device and describe its performances. Then, the device is used to study the effect of heating procedure on creep results at 1200°C and rafting during primary creep on the single crystal nickel-based superalloy MC2.

1. Introduction

Most of the published studies dealing with single crystals made of nickel based superalloys have been performed with the aim of increasing thermal stability of the γ / γ' microstructure, improving mechanical properties under thermomechanical loadings and particularly the creep lifetime up to 1050°C [1-6]. In the case of helicopter twin engines turbines, one has to consider that in the event of one engine failure during take off or cruising power an emergency power requirement is needed to ensure the safety of the flight. During this short time, the blades can experience very high temperature. Even if the overheating duration is reduced, one has to take into account γ' dissolution leading to a decrease of the volume fraction on this strengthening phase [7-11]. The thermal shock related to this emergency situation is very rapid. The purpose of this study is at first to present an experimental set-up able to generate loadings procedures much closer to real loadings and secondly to present two examples of applications of interest regarding the helicopter turbine specific loadings.

2. Description of the experimental set-up

A conventional 20 kN electromechanical machine was used as the basis for the development of the experimental set-up described here after. A low thermal inertia loading frame was designed in order to minimize thermal gradient along the gage length of the sample under heating or cooling steps. A three zones radiation furnace has been developed allowing to impose maximum heating and cooling rates
respectively equal to 3°C.s\(^{-1}\) and 10°C.s\(^{-1}\) in the range 1000 – 1200°C. The deformation of the sample was followed by using a laser extensometer. The accuracy of the strain measurement in the most severe testing conditions was assessed to be ± 2 µm. Finally, the global behavior of the experimental set-up is similar to a dilatometer in which mechanical stresses or strains can be superimposed.

3. Material of the study
The material chosen to test the experimental set-up was MC2 single crystal Ni based superalloy. The chemical composition of the alloy is given in table 1.

|            | (wt %) |
|------------|--------|
| Ni         | Eq 8   |
| Cr         | 5      |
| Co         | 2      |
| Mo         | 8      |
| W          | 5      |
| Al         | 1.5    |
| Ti         | 6      |
| Ta         |        |

It was given a classical two steps heat treatment (R1, R2) in order to optimize the microstructure. A representative \(\gamma - \gamma'\) microstructure of this alloy is presented in the figure 1. As mentioned in the introduction, the explored testing conditions have to trigger \(\gamma'\) phase dissolution. Thus, in figure 2, the evolution of the equilibrium \(\gamma'\) volume fraction for MC2 alloy up to the solvus of the \(\gamma'\) phase is presented [11]. In figure 3, as a matter of example, the \(\gamma'\) dissolution kinetics at 1200°C is also presented [12]. It is worth noting that, even at 1200°C, it takes about 60 min for the \(\gamma'\) volume fraction to reach the equilibrium value.

4. Examples of application
4.1. Effect of creep procedure
Two different testing procedures were carried on with the same final creep conditions (1200°C – 80MPa). The first one (Figure 4) simulates the conventional laboratory creep testing procedure in
terms of heating rate (HR) and thermal stabilization (TS) whereas the second one better simulates the thermal loading which is expected when an emergency event is encountered (Figure 5).

![Figure 4](image1)  ![Figure 5](image2)

**Figure 4**: Conventional laboratory creep testing procedure  
**Figure 5**: Representative procedure of an emergency event

The complete thermomechanical history of both tests is presented in figures 4 and 5. It is clear that the life time corresponding to the second procedure is longer than the one corresponding to the first type. This trend is not really surprising, since during the slow heating and stabilization time used in procedure one, $\gamma'$ precipitates have enough time to significantly dissolve. When dealing with creep rates, the Figure 6 illustrates clearly the effect of the initial $\gamma'$ volume fraction on the primary and stationary creep stages.

![Figure 6](image3)

**Figure 6**: Creep response as function of testing procedure

Here too, creep behavior related to the second procedure is logically better and secondary stage is evidenced whereas for the first loading procedure, secondary stage is more difficult to define. Fortunately, these results confirm that the creep resistance depends on the $\gamma'$ volume fraction [13].

4.2. Rafting during primary creep

Due to the excellent accuracy of the strain measurement, it became possible to investigate the dimensional evolution of the sample during the rafting process [14-19]. The first testing condition which has been explored is 1050°C under 200 MPa. An inflexion of the creep curve is observed during the early stage of the creep deformation as presented in Figure 7. Interrupted creep tests on both sides of this inflexion point (30 min and 4 h) were carried out and the corresponding microstructures characterized. Micrographs included in Figure 7 clearly show that $\gamma'$ rafting occurred during this period, as it has been observed on a different superalloy [3]. The question of the influence of an applied stress on this specific behavior raised. Then, other creep test conditions were explored, the results of which are presented on Figure 8. It appears that decreasing the applied stress seems to delay the occurrence of the inflexion. However this is certainly related to a correlated decrease of the strain rate, since the inflexion occurs for the same amount of creep strain (0.15 %) for the three tested creep conditions. This result highlights the role of plastic strain on rafting process and could be interpreted as proposed by other authors [3; 20-24] who identified the difference in terms of state of stress...
between perpendicular and parallel corridors as the driving force for rafting process and dislocation movement as the controlling kinetics parameters for coalescence.

![Graph showing creep behavior during primary stage at 1050°C under 200MPa]

**Figure 7**: Creep behavior during primary stage at 1050°C under 200MPa

![Graph showing stresses effect on the shape of the creep response at 1050°C]

**Figure 8**: Stresses effect on the shape of the creep response at 1050°C

5. **Conclusion**

The development of an experimental set-up allowing to test Ni based single crystal superalloy under testing conditions as closer as emergency events in helicopter engine allows the design of original experimental testing.

Creep properties in the temperature range corresponding to $\gamma'$ dissolution or rafting as well as the study of dimensional evolutions during microstructural modifications are interesting topics both for industrial application and for academic questioning.

**References**

[1] A. Fredholm, and J.-L. Strudel, *Proceedings of the Petten International Conference*, ed. J.B. Mariott, *et al.* (London, U.K.: Elsevier Applied science, 1987), 9-18

[2] A. Royer, A. Jacques, P. Bastie, M. Veron, *Mater. Sci. Eng. A* 319-321 (2001) 800-804

[3] P. Caron, M. Benyoucef, A. Coujou, J. Crestou, N. Clément, *ISOMALM 2000, Chennai, India*, 2000, 148-156

[4] P. Caron, C. Ramusat, F. Diologent, in *Superalloys 2008, TMS, Seven Springs*, 2008, 159-167

[5] A. Epishin, T. Link, U. Brückner, and P. Portella, *Acta Mater.* 49 (2001), 4017-4023

[6] F. Diologent, P. Caron, *Mater. Sci. Eng. A* 385 (2004) 245-257

[7] M. Soucaill, Y. Bienvenu, *Mater. Sci. Eng. A* 220 (1996) 215-222

[8] T. Grosdidier, A. Hazotte, A. Simon, *Scripta Metall. Mater.* 30 (1994) 1257-1262

[9] T. Grosdidier, A. Hazotte, A. Simon, *Mater. Sci. Eng. A* 256 (1998) 183-196

[10] A. Royer, P. Bastie, M. Veron, *Acta Mater.* 46 (1998) 5357-5368

[11] J. Cormier, PhD Thesis, University of Poitiers, ENSMA, France, 2006

[12] J. Cormier, X. Milhet, Jose Mendez, *J. Mater. Sci.* 42 (2007) 7780-7786

[13] T. Murakumo, T. Kobayashi, Y. Koizumi, H. Harada, *Acta Mater.* 52 (2004) 3737-3744

[14] J. K. Tien, S.M. Copley, *Met. Trans. 2* (1971) 215-219

[15] A. Hazotte, J. Lacaze, *Scripta Metall.* 23 (1989) 1877-1882

[16] L. Muller, U. Glatzel, M. Feller-Kniepmeier, *Acta Metall. Mater.* 40 (1992) 1321-1327

[17] M. Veron, Y. Brechet, F. Louchet, *Acta Mater.* 44 (1996) 3633-3641

[18] M. Veron, P. Bastie, *Acta Mater.* 45 (1997) 3277-3282

[19] M. Veron, Y. Brechet, F. Louchet, *Scripta Mater.* 34 (1996) 1883-1886

[20] A. Racine, A. Hazotte, *J. Physique IV* 3 (1993) 355-358

[21] T. M. Pollock, A. S. Argon, *Acta Metall. Mater.* 42 (1994) 1859-1874

[22] D. Blavette, L. Lettelier, A. Racine, A. Hazotte, *Microsc. Microanal. Microstruct.* 7 (1996) 185-193

[23] T. Ohashi, K. Hidaka, S. Imano, *Acta Mater.* 45 (1997) 1801-1810

[24] U. Hemmersmeier, M. Feller-Kniepmeier, *Mater. Sci. Eng. A* 248 (1998) 87-97