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Characteristic fatigue-creep life map of a Fe–Ni–Cr alloy melted in vacuum and in air at high temperature

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Smooth round specimens were cut from a large ESR cast-to-shape gas turbine disc (ECD) of a Fe–28Ni–14Cr alloy with a characteristic structure of coarse-branch crystal melted in vacuum and in air, respectively. The specimens were heat-treated according to a schedule of 1050 °C/4 hr, cooling in oil; and 700 °C/32 hr, cooling in air. All fatigue-creep tests were carried out under constant maximum stress at 650 °C in air. During the testing, both fatigue stress (alternating stress) and creep stress (mean stress) could be varied in simultaneously opposite directions by changing the minimum stresses. The schematic representation of the fatigue-creep testing procedure of the alloy melted in vacuum and in air are shown in Fig. 1.

Time-dependent strain–stress curves may be recorded according to the usual modes: creep, fatigue, and fatigue-creep [1]. The studies of fatigue-creep interaction concentrate on deformation and fracture mechanisms, as well as the cycle-life-predicting model etc. [2–4]. In this paper the fatigue-creep stress-cycling life curves of the alloy melted in vacuum and in air respectively under constant maximum stress with varied minimum stress are shown in Fig. 2, which indicate that the life of the alloy melted in vacuum is 5 to 10 times longer than that of the alloy melted in air. This characteristic shape of the high temperature fatigue-creep fracture life curves is different from that of both the normal fatigue S–N curves and the pure creep curves. According to the different stress dependence of the fatigue-creep life, these curves were divided into three regions: the upper region (F), the bottom region (C), and the middle region (FC). The upper region of these curves, in which the fatigue predominates the feature of the fatigue-creep interaction, is called an F region; however, the bottom region of these curves, in which creep predominates the feature of the fatigue-creep interaction, is called a C region; and the middle region between the F region and the C region, in which both fatigue and creep play an important role in determining interaction life, is called an FC region.

The combinations of a series of the fatigue-creep fracture life-stress curves with F region, C region, and FC region are called a fatigue-creep interaction fracture life map at high temperature. On the basis of the interaction life map, the fatigue-creep life can be predicted, and the full information on fracture characteristics can be provided for the tested casting alloy melted in vacuum and in air under a wide range of combinations of fatigue and creep stresses. In order to understand the effect of the overlapping between the fatigue stresses and the creep stress at high temperature on the fatigue-creep fracture life, the pure fatigue (S–N) curves of the tested alloys melted in vacuum or in air are also plotted on the fatigue-creep interaction fracture life map (Fig. 2). The shape of the fatigue-creep life curves in the F region is similar to that of the pure fatigue curve. However, it is obvious that the fatigue-creep interaction reduced the fracture life of the alloy melted both in vacuum and in air. As compared with the alloy melted in vacuum, a reduction in fatigue-creep interaction endurance of the tested alloy melted in air is more dramatic. The life of the tested alloy melted in air is 5 to 10 times less than that of the alloy melted in vacuum.

The different stress dependence of the fatigue-creep strain rate in C regions and in F regions for the tested alloy both melted in vacuum and in air is plotted in Figs 3 and 4, respectively. In F region, the strain rate increased with increasing fatigue stress; however in C region, the

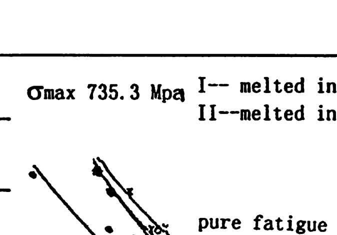

Figure 1 Schematic representation of the fatigue-creep test procedure.

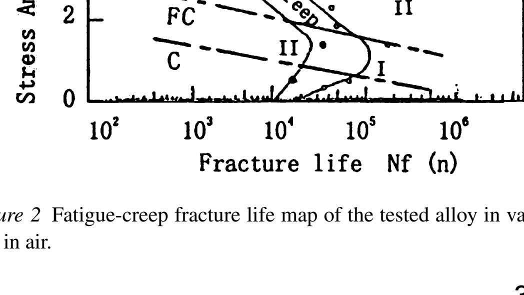

Figure 2 Fatigue-creep fracture life map of the tested alloy in vacuum and in air.

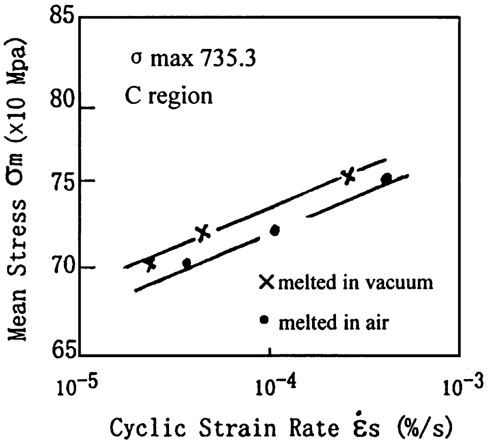

Figure 3 Cyclic strain rate vs. mean stress curves in C region.

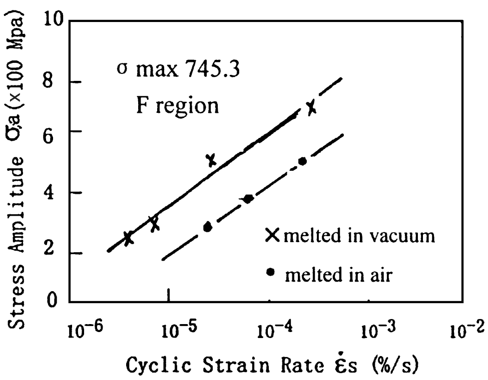

Figure 4 Cyclic strain rate vs. stress amplitude curves in F region.

strain rate increased with increasing predominant mean stress. The plot also shows an evident difference in the minimum strain rate under the same stress-overlapping condition between the alloys melted in vacuum and in air.

In general, high temperature fatigue fracture resulted from intergranular cavitations or grain boundary migration and sliding, which is induced with the cycling deformation [5, 6]. During fatigue-creep testing, the horizontal-branch crystal boundaries perpendicular to the loading axis could become a predominant path of fatigue-creep deformation and cracking initiation and expanding. The inclusions on the horizontal-branch crystal boundaries could be a reason for the accelerating cycling deformation and fracture processes of the tested alloy melted in air.

It can be well understood that the melting condition, in vacuum or in air, could play an important role in determining the fatigue-creep deformation and fracture damage of the specimens.

On the basis of the above research results and analysis, the conclusions are drawn as following:

1. A new characteristic fatigue-creep fracture life map including three types of fatigue-creep interaction regions F, C, and FC for the tested Fe–Ni–Cr alloy melted both in vacuum and in air was established and provides the full information on fracture life over a wide range of combinations of fatigue stresses and creep stresses.
2. There is a different stress dependence of both fatigue creep life and cyclic strain rate in regions F and C for both alloy melted in vacuum and in air.
3. Under the same stress condition, a reduction in fatigue-creep endurance of the alloy melted in air is more dramatic than that of the alloy melted in vacuum.

References

1. P. BERGER, G. MOULIN and M. VIENNOT, *Nucl. Instr. Meth. Phys. Res.* B **130** (1997) 717.
2. K. S. RAGHAVAN, *Intern. J. Fatigue* **13**(6) (1991) 471.
3. N. PARVATHAVARDHINI, R. K. DAYAL and J. B. GNANAMOORTHY, *J. Nucl. Mater.* **208** (1994) 251.
4. N. K. MUKHOPADHYAY, B. K. DUTTA and H. S. KUSHWAHA, *Intern. J. Fatigue* **23**(6) (2001) 549.
5. H. J. WESTWORD, in Proceedings, 4th International Conference on Fracture, Fatigue (1977) Vol. 2B, p. 755.
6. F. A. MOHAMNED, *J. Mater. Sci.* **18** (1983) 582.

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