The effects of temperature, stress, and type of materials and their interactions on the creep rate and rupture time

Dr. Pravin S. Nerkar[1], Ms. Himani H. Nawalkar [2], Ms. Simran A. Thakre [3]

[1,2,3,] Mechanical Engineering Department,

St Vincent Pallotti College of Engineering and Technology, Nagpur-441108, Maharashtra, India.

**Corresponding author Email:psnerkar@yahoo.co.in*

ABSTRACT

The prediction of crack propagation at elevated temperatures is important and this paper provides a critical review of available information and models for behavior. Creep is very slow and permanent deformation of materials at constant temperature and under constant stress. It is a phenomenon accelerated by higher temperatures at stress level below yielding strengths. Knowledge of creep deformation is necessary for design and application of materials at elevated temperatures. This Review focuses on aspects with particular reference to creep-fatigue failure diagnosis. Creep-fatigue cracking due to a spectrum of loading conditions ranging from pure cyclic to steady loading with infrequent off-load transients.The possible grain-boundary behaviors, such as the mismatch behavior at grain boundary due to creep deformation, are studied. It implies that at high crack growth rates these hold-time effects arise mostly from creep-fatigue interaction rather than environment fatigue interaction. The effects of temperature, stress, and type of materials and their interactions on the creep rate and rupture time were considered. Results showed that the main effects of factors and their interactions are significant on the creep rate and rupture time. The effects of temperature and stress are factors which affect creep phenomenon. In the fast fracture of high strength, low toughness materials and in fatigue crack growth, it is established that data from tests can be confidently applied to predict the integrity of a structure or crack extension in service using sharp crack stress intensity factors. More recently, a study of fatigue crack initiation from sharp notches in mild steel has shown that the number of cycles to initiate a crack also be calculated using stress intensity factors. In components which operate at elevated temperatures there is a need to develop methods which describe the growth of crack-like defects in creep conditions.

Keywords: Creep;Creep-Fatigue Interaction; Stress; Temperature;Permanent deformation

1. Introduction

The process of fatigue failure is physically and macroscopically described by crack-growth behaviour. The situation is complicated when creep is also present because this provides an additional mechanism for plastic deformation and crack growth. In the case of creep-fatigue, an engineering structure fails when the crack length achieves a critical value. The total injury is the accumulated result of cycle count, temperature, and period (frequency). Some of the ways this has been model. The process of fatigue failure is physically and macroscopically described by crack-growth are to prove a mathematical representation of the various components of fracture mechanics Under repeated stress, the crack generally started as a transgranular fissure and adjusted to associate intergranular creep crack at some length of the crack. The transition point moved to a later stage of crack propagation as the period of repeated stress increased. This transition phenomenon could be explained by assuming that the two crack propagation processes, the transgranular fatigue crack and the intergranular creep crack, are possible under repeated stress conditions and that the one with the higher rate actually occurs.

2. Mechanism of Creep-Fatigue Cracking

The development of creep-fatigue damage in most power plant steels depends on temperature, strain range, strain rate, hold time, and the creep strength and ductility of the material [1,2,3,]In the absence of a significant hold time (and/or at relatively high strain rates), crack initiation and growth is fatigue dominated, even at high application temperatures (Figure 1a). With increasing hold time (and/or decreasing strain rate) at high temperatures, the creep damage within the structure becomes increasingly influential, to the limit beyond which crack development becomes fully creep dominated (Figure 1b). At intermediate hold times and strain rates, fatigue cracking interacts with creep damage developing "consequentially" or "simultaneously" resulting in accelerated crack propagation and reduced crack initiation endurance (Figure 1c,d and Figure 2). The extent of any interaction increases with decreasing creep ductility [3]. The interaction of creep and fatigue isn't restricted to the buildup of injury. Deformation interactions are also influential, and in a dominant way for a number of alloys [2].

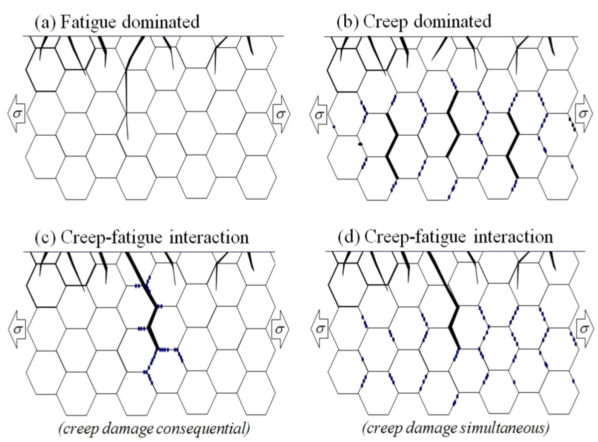

Figure 1. Creep-fatigue cracking mechanisms: (a) fatigue dominated; (b) creep dominated; (c) creep-fatigue interaction (due to "consequential" creep damage accumulation); (d) creep-fatigue interaction (due to "simultaneous" creep damage accumulation).

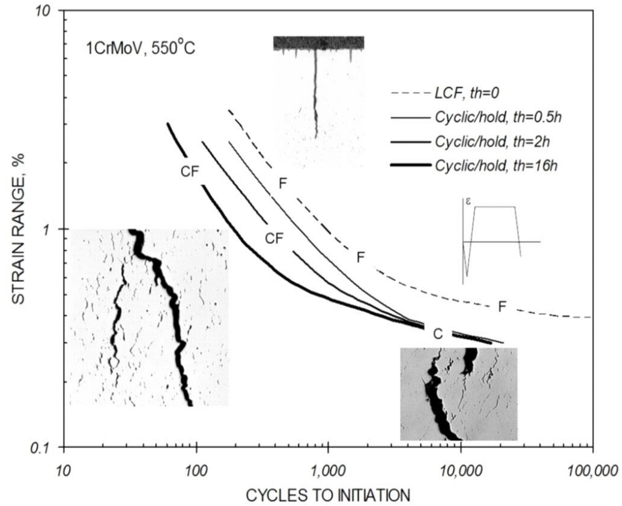

Figure 2. Influence of hold time on the cyclic/hold creep-fatigue endurance of 1CrMoV steel at 550 °C wherever crack development is known as being pure creep (C), pure fatigue (F) or creep-fatigue (CF). LCF = Low Cycle Fatigue.

2.1 Creep Ductility

Creep plasticity is powerful in determinative the extent of creep-fatigue interaction (Figure 3). When creep ductility is high, creep voids typically tend to form predominantly at inclusions as a consequence of particle-matrix cohesion (Figure 4a), creep dominated cracking tends to be transgranular rather than intergranular , and creep-fatigue failure is due to damage summation with insignificant interaction (linear damage summation, see inset with reference to Figure 6). When creep plasticity is low, creep cavities usually kind at grain boundaries, and also the extent of creep-fatigue interaction is high (Figure 5b).

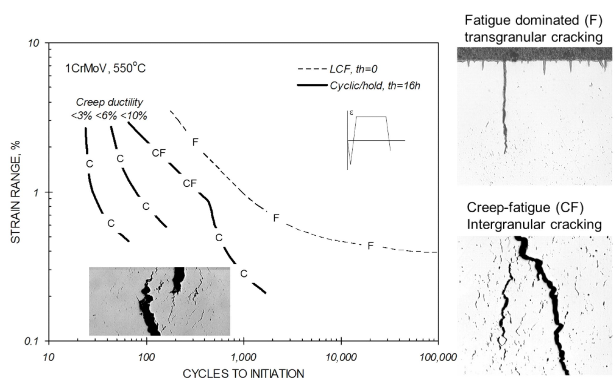

Figure 3. Influence of creep ductility on the cyclic/hold creep-fatigue endurance of 1CrMoV steel at 550 °C

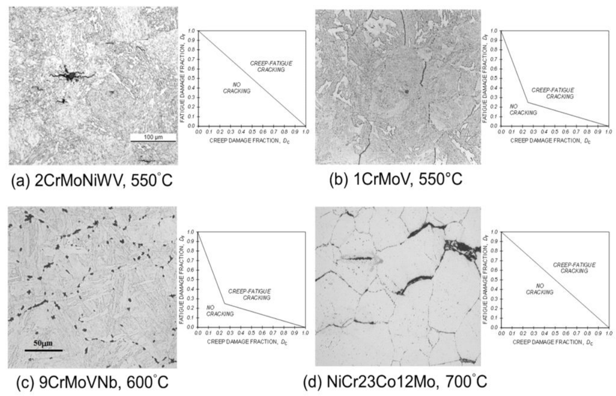

Figure 4. Creep damage development: (a) transgranular due to particle-matrix decohesion in creep ductile 2CrMoNiWV steel at 550 °C; (b) intergranular in a 1CrMoV steel at 565 °C; (c) intergranular in a 9CrMoVNb steel at 600 °C; (d) intergranular in a NiCr23Co12Mo alloy at 700 °C

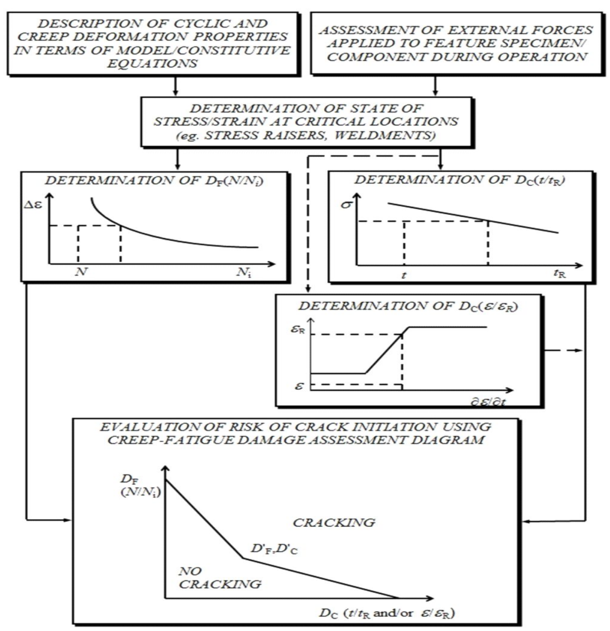

Figure 5. Influence of creep-ductility on creep-fatigue cracking mechanisms

In practice, the situation is not always as simple as this. It is typical for precipitation-strengthened ferritic steels (Figure 4b,c), it can also occur in higher ductility solid solution strengthened alloys (e.g., Figure 4d).

Indeed, during this category of steel, the microstructural proof seems to point that creep-fatigue deformation interactions are additional necessary than creep-fatigue injury interactions [2,4,5,6]. The sizes of sub-grains that develop due to creep-fatigue loading are much greater [5,6], and provide a means of quantifying the extent of deformation interaction in steels that do not always 0exhibit classical evidence of creep-fatigue damage interaction [6]. This type of familiarity with m0aterial conditions is invaluable for effective and efficient failure diagnosis.

3. Mechanical Analysis of Creep-Fatigue Cracking

3.1. Crack Initiation

While there are a number of published and in-house procedures available to assess the risk of creep-fatigue crack initiation in high-temperature components (e.g., [7,8,9,10]), most can be represented by the generic flow diagram shown in Figure 6. An important step in any creep-fatigue assessment procedure could be a determination of the state of stress and strain at the essential location within the element. This requires information of the external forces and thermal transients veteran by the structure throughout service operation, and representations of the cyclic and creep deformation properties of the material(s) of construction in terms of model constitutive equations (e.g., [11]). Irrespective of whether the local stress-strain state is determined by approximate analytical solutions or finite element analysis (FEA), the constitutive model options are generally the same.

With this data, fatigue and creep damage fractions can be determined. Fatigue damage fraction is commonly determined in terms of cycle number fraction, N/Ni(Äå), where N/Ni(Äå) can be the low cycle fatigue (LCF) or the cyclic/hold creep-fatigue test crack initiation endurance (depending on the procedure). The method of determination of creep harm fraction will depend upon whether or not it's accumulated because of primary (directly applied) or secondary (self-equilibrating) loading. Regardless of the approach adopted, the fabric properties needed area unit derived from the results of typical creep-rupture test

Typically such diagrams are constructed from the results of cyclic/hold (LCF with hold time) creep-fatigue tests or thermo-mechanical fatigue (TMF) tests, which indicate the extent of any creep-fatigue interaction of the fabric of interest underneath exactly well-known thermo-mechanical boundary conditions (e.g., insets in Figure 4 and Figure 5).

3.2. Crack development

Crack development thanks to creep-fatigue loading might occur (i) at intervals the range of a cyclic plastic zone when the crack is physically tiny, i.e.,

(a) (b)

Creep-fatigue-oxidation interaction is accommodated through the AT, function in Equation (2) which accounts for any influence of prior creep and oxidation damage at the crack tip, and may be determined experimentally (e.g., Figure 8) [12]. For steady-state creep conditions ahead of the crack tip, the creep rate-dependent C* parameter provides an acceptable size and geometry-independent function for correlating creep crack growth rates for long cracks [13]

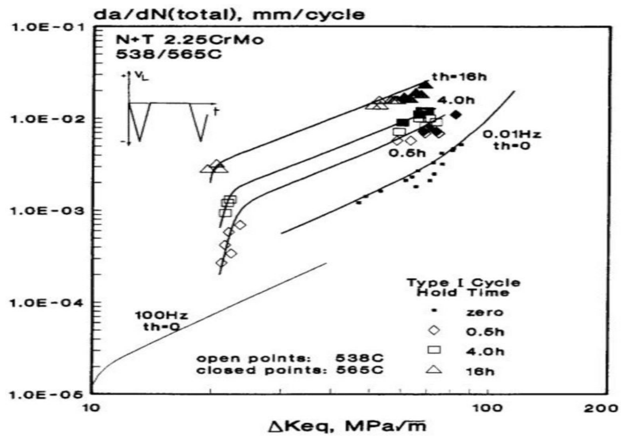

fig.6 Creep- fatiguge and crack gorwth rate

In the short crack regime (Figure creep-fatigue crack growth rates may be expressed as a function of total strain range, as in Equation (4) [14,15,16], although other correlating parameters may be employed [16].

Microstructurally short Stage I fatigue cracks typically extend along persistent slip bands [17] to a depth of 1–2 grain diameters before becoming Stage II cracks propagating in a transgranular manner normal to the most principal stress [18,19].

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4. CONCLUSION

Creep-fatigue cracking can be due to a spectrum of loading conditions ranging from pure cyclic to mainly steady loading with infrequent off-load transients. These require a range of mechanical analysis approaches, a number of which are reviewed. The effectiveness and efficiency of the diagnosis of failures due to creep-fatigue loading are enhance by familiarity with the characteristics of the material of the failed component which can come from the routine post-test examination of laboratory specimens.

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