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CREEP AND STRESS RUPTURE

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ABSTRACT
Metal components can slowly and continuously deform under load below the yield stress at high temperatures. This time dependent deformation of stressed components is known as creep. Deformation leads to damage that may eventually lead to a rupture. Creep voids typically show up at the grain boundaries and in later stages form fissures and then cracks Thermal fatigue cracks usually initiate on the surface of the component.
Keywords: creep, stress, deformation

1. INTRODUCTION
Metal components can slowly and continuously deform under load below the yield stress at high temperatures. This time dependent deformation of stressed components is known as creep. Deformation leads to damage that may eventually lead to a rupture. Creep voids typically show up at the grain boundaries and in later stages form fissures and then cracks Thermal fatigue cracks usually initiate on the surface of the component.

Creep is a time-dependent deformation of a material while under an applied load that is below its yield strength. It is most often occurs at elevated temperature, but some materials creep at room temperature. Creep terminates in rupture if steps are not taken to bring to a halt.

Stress rupture testing is similar to creep testing except that the stresses are higher than those used in a creep testing. Stress rupture tests are used to determine the time necessary to produce failure so stress rupture testing is always done until failure.

Creep is defined as the time-dependent strain that occurs under load at elevated temperature and operates in most applications of heat-resistant high-alloy castings at normal service temperatures. The stress that produces a specified minimum creep rate of an alloy or a specified amount of creep deformation in a given time (for example, 1% of total 100,000 h) is referred to as the limiting creep strength, or limiting stress. Creep occurs when a metal is subjected to a constant tensile load at an elevated temperature. Undergo a time-dependent increase in length. Since materials have its own

different melting point, each will creep when the homologous temperature > 0.5. The shape of creep curve will slightly change according to the applied stress at a constant temperature.
At high temperatures, metal components can slowly and continuously deform under load below the yield stress. This time dependent deformation of stressed components is known as creep. Deformation leads to damage that may eventually lead to a rupture.

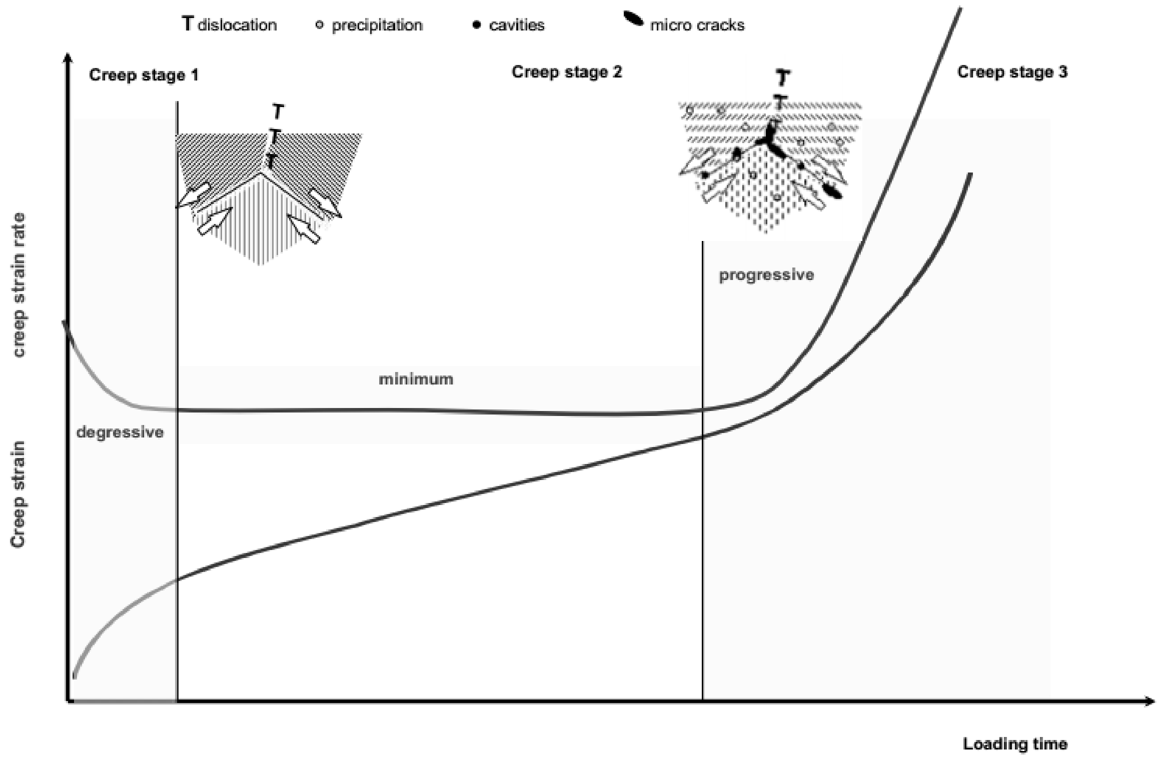

Figure 1. Development of creep strain and creep strain rate over time and schematic illustration of micro structural changes in material

2. CREEP PHASES

During the phase of primary creep, the creep strain rate decreases, and the main cause of this phenomenon is seen in the increase of density of dislocations in the material. In the phase of secondary creep, a balance of hardening and softening mechanisms is present; therefore the creep strain rate is almost constant. Aside from changes in the micro structure like formation of precipitates, other thermally activated processes in the microstructure can take place like: pearlite decomposition, coagulation and precipitation of carbides etc. These processes are independent from material, time and temperature. All the changes in the microstructure up to this point are reversible, and their effects can be mitigated trough i.e. heat treatment. Irreversible creep damage appears in the form of cavities, dependent on material and load (stress, temperature and time). In connection with the metallurgical changes (sub-grain growth, particle coarsening and increase of particle distances), the creep strain rate increases significantly. As the damage progresses, chains of cavities appear mostly on the grain boundaries, as well as micro cracks. They tend to grow in the direction of load. This phase is known as tertiary creep phase. The optical-microscope visible damage in the form of creep cavities is dependent on type of material and its microstructure, temperature and load (stress and multiaxiality). Multiaxiality of the load reduces the deformability of the material, therefore promoting the cavitations processes.

3. CREEP DAMAGE AND STRESS RUPTURE

Creep damage is found in high temperature equipment operating above the creep range (material dependent). Heater tubes in fired heaters are especially susceptible as well as tube supports, hangers and other furnace internals. Piping and equipment, such as hot-wall catalytic reforming reactors and furnace tubes, hydrogen reforming furnace tubes, hot wall FCC reactors, FCC main fractionator and regenerator internals all operate in or near the creep range. Low creep ductility failures have occurred in weld Heat Affected Zones (HAZ) at nozzles and other high stress areas on catalytic reformer reactors. Cracking has also been found at long seam welds in some high temperature piping and in reactors on catalytic reformers. Welds joining dissimilar materials (ferritic to austenitic welds) may suffer creep related damage at high temperatures due to differential thermal expansion stresses. Thermal fatigue cracks usually initiate on the surface of the component. They are generally wide and often filled with oxides due to elevated temperature exposure. Cracks may occur as single or multiple cracks. Thermal fatigue cracks propagate transverse to the stress and they are usually dagger-shaped, transgranular, and oxide filled. Cracks often start at the end of an attachment lug and if there is a bending moment as a result of the constraint, they will develop into circumferential cracks into the tube. Water in soot blowers may lead to a crazing pattern. The predominant cracks will be circumferential and the minor cracks will be axial.

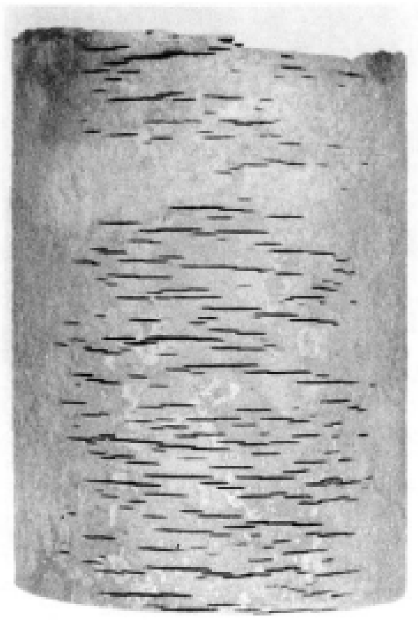

Figure 2. Typical thermal fatigue/thermal shock damage Short Term Overheating – Stress Rupture

Permanent deformation occurring at relatively low stress levels as a result of localized overheating. This usually results in bulging and eventually failure by stress rupture. It can occur in all fired heater tube materials and common materials of construction. Temperature, time and stress are critical factors. Usually due to flame impingement or local overheating. Time to failure will increase as internal pressures or loading decrease. Local overheating above the design temperature is also critical factor. Loss in thickness due to corrosion will reduce time to failure by increasing the stress. Local overheating is usually much higher than the usual operating temperature, i.e. in the ranges well above 400-500°C for typical steels used in the process or power industry. The damage mechanism is tightly linked with the creep phenomena, i.e. underlying micro-structural mechanisms are the same.
Damage is typically characterized by localized deformation or bulging on the order of 3% to 10% or more, depending on the alloy, temperature and stress level.

4. PREVENTION / MITIGATION

Minimize localized temperature excursions. Fired heaters require proper burner management and fouling/deposit control to minimize hot spots and localized overheating. Utilize burners which produce a more diffuse flame pattern. In hydroprocessing equipment, install and maintain bed thermocouples in reactors and minimize the likelihood of hot spots through proper design and operation. Maintain refractory in serviceable condition in refractory lined equipment.

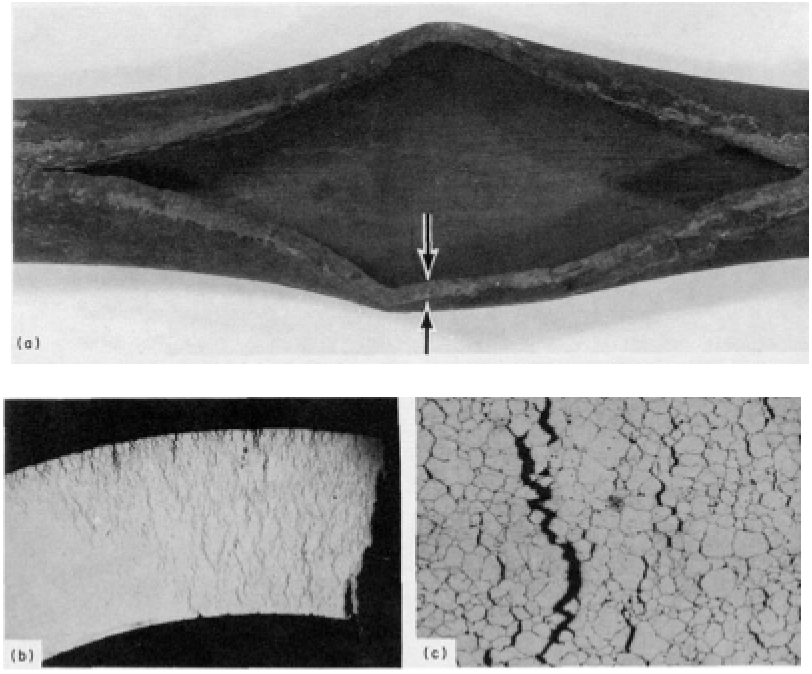

Figure 3. Overheating example - ASME SA-213, grade TP321H superheater tube that failed by thick-lip stress rupture

Changing of the slope indicates structural changes in the material , i.e., transgranular intergranular fracture, oxidation, recrystallisation, grain growth, pheroidization, precipitation metal welds have been used in piping around FCC reactors and regenerator vessels, in fired heater applications where the heater tube material changes from 5Cr or 9Cr to 300 Series SS, and in transitions in hydroprocessing reactor outlet piping from overlaid low alloy CrMo nozzles or piping to solid 300 SeriesSS piping. All superheaters and reheaters that have welds between ferritic materials (1.25Cr-0.5Mo and 2.25Cr-1Mo) and the austenitic materials (300 Series SS, 304H, 321H, and 347H) are affected.

5. CONCLUSION

Cracking may be axial or circumferential, or both, at the same location. In steam generating equipment, cracks usually follow the toe of the fillet weld, as the change in section thickness creates a stress raiser. Bulging and distortion can be significant at low stresses, as temperatures increase.
Ruptures are characterized by open “fishmouth” failures and are usually accompanied by thinning at the fracture surface

6. REFERENCES

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