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ASSESSMENT OF MICROSTRUCTURE DEGRADATION OF CREEP EXPOSED BOILER STEELS

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ABSTRACT
Under the influence of temperature and stresses, the heat resistant materials react by creeping. Boiler components subjected to creep have a limited lifetime. Creep and material structure evolution are tightly related and according to this rule a number of studies have been performed in order to relate micro structural investigation and service exposure or residual life. The determination of the structural conditions and the materials exhaustion of creep exposed power plant boiler components is increasingly carried out by field of metallography. For assessment of damage and of the risk associated with failure it is necessary to know the potential mechanisms of degradation and the rate of accumulation of damage. VGB-TW 507 represents guideline for the assessment of microstructure and damage development of creep exposed materials for pipes and boiler components.
Keywords: creep, microstructure, life assessment

1. INTRODUCTION
Many engineering components in, for example, conventional and nuclear power plant, chemical plant, aero engines and so on, operate at temperatures high enough for creep to be an important design consideration. The failure of components operating at elevated temperatures can have catastrophic effects. Therefore, the development of safe design procedures, material behaviour modelling and assessment of microstructure degradation has been an ongoing process.
The assessment of the remaining lifetime of a component which is operated under known conditions for a long period of time is known as remanent life assessment [1]. The assessment procedures often involve the examination of a sample of material taken from the component in question, the measurement of its properties, or the examination of the extent of creep damage. These observations are then used in conjunction with analytical predictions to assess the remaining safe period of component operation.

2. CLASSIFICATION OF CREEP DAMAGE
Creep is one of the most serious high temperature damage mechanisms. It involves time-dependent deformation and high temperature creep cracking generally develops in an intercrystalline manner in components of engineering importance that fail over an extended time. Classification of creep damage in boilers has been made using the largely qualitative approach of Neubauer and Wedel based on the distribution of creep voids and microcracks observed by in situ metallography and illustrated schematically in Figure 1 [2].

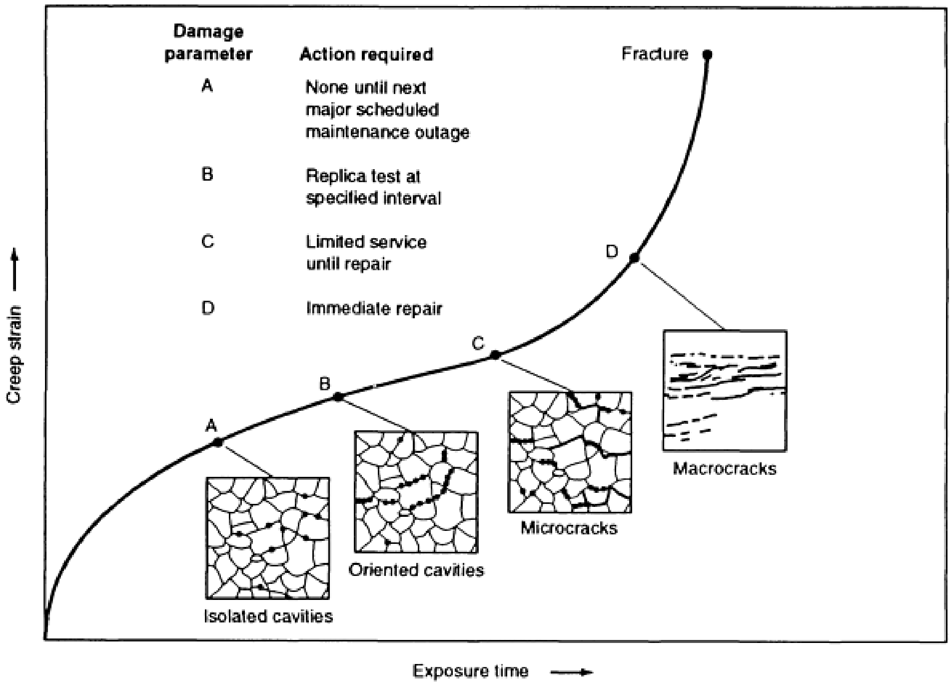

Figure 1. Neubauer`s classification of creep damage from observation of replicas and consequent action to be taken [2].

The concept of microvoid formation at grain boundaries has been mainly studied and developed in the 1970's and is commonly recognised and applied in all European countries with the Neubauer classification and derived methods [3]. The principle is based on the fact that creep evolution of heat resistant steels is related to the appearance of cavities some time before rupture. These cavities gradually form microcracks by interlinkage and at the end come to initiate the rupture. Size and density of the cavities increase as creep progresses from secondary to tertiary. Cavity size is largely dependant also on material type, however it is in the range of micron size (often also lower); therefore they are usually called "microvoids" or "micro-cavities". Due to their small size, they cannot be detected by conventional non-destructive techniques such as penetrant testing, ultrasound testing, magnetic testing, radiography testing, and metallographic investigation is required.

Evolution of Neubauer classification can be found in different European countries varying from a simplified approach to a more detailed classification [3]. A simplified approach of Neubauer damage classification can be found in the Italian ISPESL Guidelines 002 (reference document for creep classification applied in Italy) where the Neubauer classification is limited to the five different grades with an indicative representation of damage aspect. Another revision of Neubauer classification is presented in the German VGB-TW 507 "Guidelines for the assessment of microstructure and damage development of creep exposed materials for pipes and boiler components" that is considered as one of the most updated reference document also in other European countries. The proposed damage rating is presented in Table 1.

Table 1. VGB Guideline classification [4].

Assessment class	Structural and damage conditions
0	As received, without thermal service load
1	Creep exposed, without cavities
2a	Advanced creep exposure, isolated cavities
2b	More advanced creep exposure, numerous cavities without preferred orientation
3a	Creep damage, numerous orientated cavities
3b	Advanced creep damage, chains of cavities and/or grain boundary separations
4	Advanced creep damage, microcracks
5	Large creep macrocracks

3. MICROSTRUCTURE DEGRADATION ACCORDING TO TECHNICAL NORMS

Components that operate at elevated temperatures can fail because of excessive creep deformation or cracking. Failure by cracking can be viewed as comprising three stages: crack initiation, crack propagation, and final failure of the component once the crack reaches a critical size. Therefore, life-assessment techniques aim to quantify uniform or localized incipient damage prior to crack initiation, the rate at which cracks grow, and the critical crack size that will lead to final failure.

Metallographic replication methods have been developed that can correlate either cavitations evolution or changes in carbide spacing with creep-life expenditure. It has been observed that, in many structural applications, cavitation is the principal damage mechanism in brittle zones, and high-stress regions in the base metal. In other cases, carbide coarsening can provide a better indication of life consumption [5].

The determination of the structural condition and materials exhaustion of creep exposed power plant components is increasingly carried out by field metallography, examining the relevant components. VGB-TW 507 represents guideline for the assessment of microstructure and damage development of creep exposed materials for pipes and boiler components. This guideline covers the pipe materials presented in Table 2.

Table 2. Pipe materials covered by VGB-TW 507[4].

DIN nomenclature	Material Nr. acc. DIN 17175
13CrMo4-4	1.7335
10CrMo9-10	1.7380
14MoV6-3	1.7715
X20CrMoV12-1	1.4922
X8CrNiNb16-13 (16)	1.4961 (1.4981)

The microstructure is primarily dependent on the operating temperature, while the damage is mainly controlled by stress or strain. This guideline is therefore restricted to creep exposed components. Depending upon the provision of materials it was anticipated to present microstructures of pipes, bends, fittings and headers. The assessment of the structure was performed on selected components, with heat treatments in accordance with the respective standard. The structures often stabilize and unify after prolonged thermal exposure. For this reason service exposed materials exceeding 100.000h were selected.

This guideline is consisted of photos of real microstructures of all above mentioned materials for damage classes from 1 to 5. Figure 2 shows replica from the material of bend (13CrMo4-4) with damage assessment class 3a – creep damage, numerous orientated cavities [4].

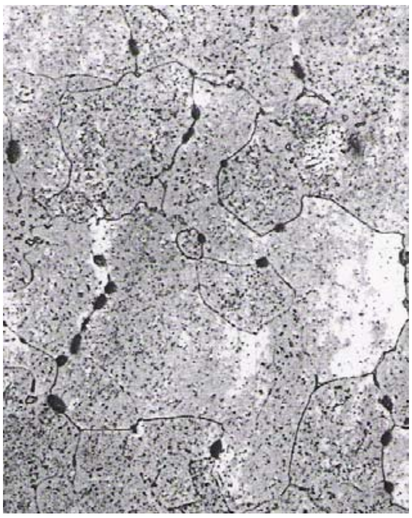

Figure 2. Damage assessment class 3a - 13CrMo4-4,
Replica: mechanical polishing, spray etching with 3% HNO_3, magnitude 500x [4].

Major limitation of the replica is the necessity to reduce the examined area to a very limited extension if compared to actual component dimension. The preliminary correct identification of the position in component that should be replicated is thus a very critical phase, in order to be sure that the replica examined is representative of the most probabilistic damaged area.
Location of area to be examined by means of replica is usually based on the analysis of plant operating condition correlated to component design dimensions and material type. Pre-replica measurement of actual thickness component parts by means of ultrasound testing is also recommended in order to detect eventually existing defined area where local corrosion or other actions can cause thickness reduction and consequently higher stresses with more probabilistic creep damage [3].

4. FINAL REMARKS

The knowledge of the structure and degree of damage could be essential for the assessment of residual service life and damage analysis respectively. It should however be pointed out that the above mentioned knowledge alone does not allow a prediction of the residual service life. Besides the knowledge of material properties after service exposure, an assessment of material exhaustion is required under the consideration of a temperature and stress analysis. VGB-TW 507 guideline yields no information with respect to the used strain [4].
It’s important to remark that all other (but cavities) microstructural observed parameters need to be evaluated on the basis of the as received material correspondent status in order to avoid any misleading deduction from generic or recommended microstructure variation not actually correlated to service exposure.
Evaluation of microstructural evolution in exposed to service materials is a key tool for a correct evaluation of material status and allowable service extension. A reliable life assessment should be made not only by means of microstructural inspection but it’s preferable that together with other inspections the same is included.
Among the different aspects that can be observed the evaluation of microcavitation presence and creep damage evolution seems to be, for the widely applied ferritic low alloyed steels, the most consolidated approach and the evolution of Neubauer classification with subclassification in particular of grade 2 and 3 (that corresponds to the longest part of a component life) should be continued and encouraged [3]. For every other microstructural aspect (except microcavities), whatever is the monitored one it is very important that the evaluation is made by comparison with the original (virgin material) status.
In implementing life-assessment procedures, the appropriate failure definition that is applicable to a given situation must be determined at the outset. The purpose for which the assessment is being carried out also must be considered. Determining the feasibility of extending plant life may be one objective, but a more-common objective is to set appropriate intervals for inspection, repair, and maintenance. In this context, life-assessment procedures are used only to ascertain that failures will not occur between such intervals. It should never be assumed that, having performed a life-assessment study for a 20-year life extension, one can then wait 20 years before conducting interim monitoring. Periodic checks to ensure the validity of the initial approach are essential. Thus, life extension should be viewed as an ongoing, rather than a one-time, activity. The various tools and techniques available should be used in a complementary and cost-effective way, rather than as competing techniques [5].

5. REFERENCES

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