e-Atlas – *the database of ageing microstructures*

Microstructural degradation in metals and alloys results from a variety of ageing mechanisms, physical or chemical processes such as low or high temperature exposure, fatigue, creep, cracking, embrittlement, stress corrosion cracking, wear, erosion, corrosion and oxidation. Ageing in this case is not always associated with the age of a component or equipment. The term 'ageing' is defined more to be *"the effect whereby a component suffers some form of material degradation and damage (usually, but not necessarily, associated with time in service) with an increasing likelihood of failure over the lifetime"*.

Background

Problems occurring due to ageing have recently become more prevalent in the plant performance due to variations in plant operating conditions. The objective for the plant engineer is to know how to relate the operating conditions to the condition of the components and later to assess the performance and the life of those components. One of the techniques to determine the integrity and remaining life of a high temperature industrial plant is to study its components' microstructural features such as grain boundary deterioration, precipitate formation and coarsening, voids or damage initiation and growth etc. that influence and determine material integrity and life. For high temperature plant such as power, petrochemical, chemical etc., metallographic examination by means of replication is a common practice to assess component condition and plant remaining life. For example, it is well known that in C-Mn or low alloy steels the microstructure deteriorates with service time due to the breakup of carbides giving rise to the *spheroidisation* of the pearlite. In the case of petrochemical plant *carburisation* or *metal dusting* are common problems.

In high temperature plants, common components used for the construction of boilers and heat recovery steam generator components are for example: ferritic, bainitic and advanced martensitic steels (P91, P92 etc.). By observing the microstructural changes of these materials over their service life through precipitate coarsening and the development of cavities under creep conditions, an estimation of remaining life of the component can be made. General methodology is that the material microstructure is assessed relative to a limited microstructure database that a company may have of similar materials with known life time and then make a qualitative assessment of the remaining life of a component. It is usually followed, where possible, by testing the actual component material in order to make quantitative assessment of component remaining life. However, mechanical testing of miniature specimens using a spare thickness over and above the design minimum has to be available. I also takes time to cut out 'boat samples', build up test specimens and then conduct time-dependent creep rupture testing. Thus one has to rely on the replica assessment for more immediate life estimate.

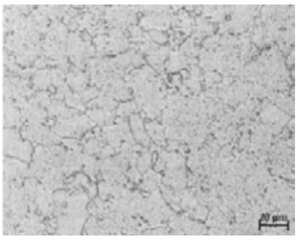
Information from the microstructure of component can also be used in the maintenance programme of plant. Comparing the microstructure with the data of the in-service components will enable users to maximize life of the equipment. For example in the petrochemical industry, a reformer tube costs approximately $20,000 each, and in one furnace there are approximately 440 tubes. Replacing tubes before they reach the end of their useful life is a waste of valuable maintenance cost. The microstructure data of the in-service components furthermore can be utilized to study the damage development as a result of operating condition for preventive plant maintenance.

e-Atlas

European Technology Development Ltd (ETD) has developed an electronic atlas (*e*-Atlas) of replicas of the commonly used steels in the power and petrochemical industry and their relationship with the material life as a function of operating time and temperature. The micrographs are accompanied by relevant information of the microstructural degradation and damage mechanisms. The *e*-Atlas consists of a microstructural catalogue of ex-service components including those with very long service durations of 30 years or more and is mainly based on replica records from a variety of components from power and petrochemical plants. It includes approximately 10,000 replicas and covers a broad range of materials such as A335 P22, A335 P11, X20, 1CrMoV, 10CrMo 910, 12CrMo910, 14CrMo3, 14MoV63 etc. The major components are superheater and reheater headers, tubes of several internal pressure levels, drum body, steam line, drum nozzles, down comers pipes, evaporator panels etc.

The user of *e*-Atlas will be able to compare and contrast the condition of in-service micrographs with an equivalent set of micrographs (e.g. similar stress, temperature and service conditions) contained in the *e*-Atlas database. The equivalent set of micrographs will have a known remaining life. From this the user will be able to determine with a greater degree of confidence, a qualitative assessment of the remaining life of the components. The *e*-atlas is aimed at fulfilling the requirement of many power and petrochemical plants which need to compare their very old plant components microstructure with reference microstructure and thus have a higher degree of confidence in the integrity and remaining life of their plant.

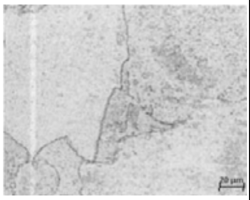
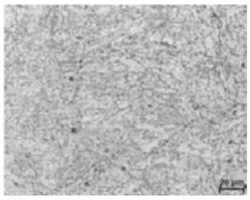
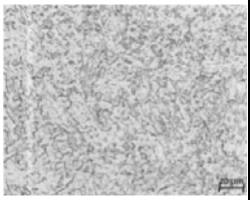
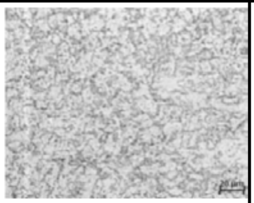
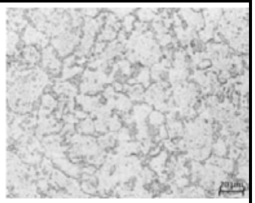
European Technology Development Ltd. Fountain House, Cleeve Road, Leatherhead, Surrey KT22 7LX +44 1372 363111 www.etd-consulting.com enquiries@etd-consulting.com



Example

If a plant has the microstructure of a superheater component with the operating conditions of 19MPa pressure, 540°C temperature and was in service for 100,000 hrs (Figure 1). They can easily make comparison of their component condition with a reference replica from *e*-Atlas database (**Figure** 2).

Fig 1: Superheater component microstructure

Parent Metal	Heat Affected Zone	Weld Metal	Heat Affected Zone	Parent Metal
				
DL = 1 Hardness = NA Magnific. = 500 X Ferrite & Bainite	DL = 2 Hardness = NA Magnific. = 500 X Ferrite, Bainite & Microcavities	DL = 1 Hardness = NA Magnific.= 500 X Bainite	DL = 1 Hardness = NA Magnific. = 500 X Ferrite & Bainite	DL = 1 Hardness = NA Magnific.= 500 X Ferrite & Bainite

Note:
NA=Not Available
DL=Damage Level
1. Free of cavities, 2. Single and isolated micro-cavities, 3. Orientated micro-cavities, 4. Micro-cracking, 5. Macro-cracking

Fig 2: Reference Replica in *e*-Atlas Database: Superheater Manifold

<u>*Note*</u>*:* The cross weld replica in Figure 2 has been taken from an A335P22 material, superheater manifold component containing a circumferential butt weld. The service conditions of the component were: pressure 19.6 MPa; temperature 540°C. The component was in service for approximately 208,293 hrs. It is noted that the heat affected zone of the component has already reached to the damage level 2, meaning that it contains single and isolated microcavities. The above plant can therefore compare microstructure of in-service plant components to make preliminary predictions of their remaining life.

Remaining Life Based on Replica Records

It has already been discussed that the plant can predict the service life of the component by comparing with the reference replicas from *e*-Atlas database.

Metallographic surface replication and predictive analysis of creep damage have been used to provide a semi-quantitative life assessment. The continuum damage approach, such as that due to Kachanov and Rabotnov, has made it possible to relate the degree of damage to the life fraction consumed. The practical measure of the degree of damage is for example the-so called ‘A Parameter’ which is given by the number fraction of cavitated grain boundaries [Ref: Shammas M. *Remanent life assessment of ferritic weld heat affected zones by a metallurgical measurement of cavitation damage – the “A” parameter*. In *Refurbishment and Life Extension of Steam Plant*, IMechE, UK, 1987].

More recently cavity density (number of cavities per unit area or volume) has been used as damage quantification parameter for remaining life estimation. Replicas of a material made at different stages of its creep life can provide information on cavity growth at critical or more vulnerable locations or zones in a material, such as the heat affected zone (HAZ). In the tertiary creep stage, the base material may have low residual creep ductility with resultant fast cavity growth. The numbers of cavities or voids formed are associated with the volume change due to void formation and growth to provide the constraint cavity growth.

For example, we have a microstructure (Figure 3) and we need to know the remaining life. The calculation shows that, A-Parameter is roughly counted 0.461 over 201 traverses line where grain boundaries are 453 ±2.58, cavitated grains are 209 ± 2.19. In general, A-Parameter values between 0.446 and 0.476 are expected. Using the ‘A’ parameter, the remaining life is calculated to be 81,295 hrs.

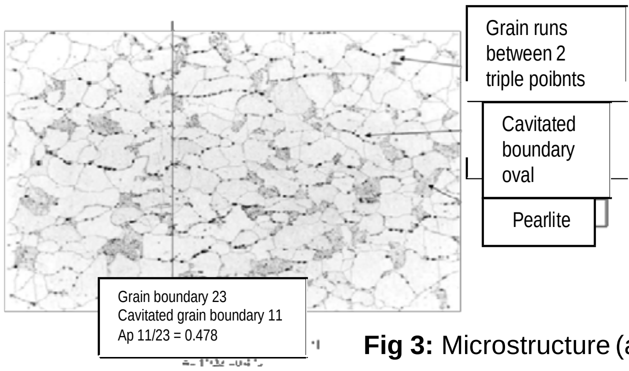


Fig 3: Microstructure (a)

Conclusion

E-Atlas opens a great opportunity for the plant to compare the microstructure of in-service components with the reference microstructure from the database. E-Atlas is a tool to assist the plant engineer to identify the microstructure degradation and conditions i.e. cavities, voids or other microstructure degradation.