

## Evaluation of the Processes Causing the Constructional Materials Degradation

Pavel Polach<sup>1</sup>

**Abstract:** The paper deals with the tasks solved in the framework of the research plan “Research into Service Degradation of Advanced Constructional Materials”, which has been solved in ŠKODA VÝZKUM s.r.o. since the year 2004 and will be finished in 2010. The paper is focused on the tasks solved in the last two years of the research plan solution, i.e. 2009 and 2010. The objective of the research plan is the development of both existing and new methodologies describing in a complex way degradation of new types of materials applied at production of engineering equipment, structures and their parts, used in the power and the transport industry.

**Keywords:** Material degradation, Experimental measurements, Computer simulations

### 1. Introduction

The objective of the research plan MSM 4771868401 “Research into Service Degradation of Advanced Constructional Materials” is the development of both existing and new methodologies describing, in a complex way, degradation of new types of materials applied at production of engineering equipment, structures and their parts, used in the power and the transport industry. The plan has been solved in ŠKODA VÝZKUM s.r.o. since the year 2004 and will be finished in 2010. It is supported by the Ministry of Education, Youth and Sports of the Czech Republic. The paper is the continuation of the paper [1] (which dealt with tasks solved in the years 2004 to 2008). This paper is focused on the tasks solved in the last two years of the research plan solution, i.e. 2009 and 2010.

The solving of the research plan is divided into partial tasks [1-4] which were defined on the basis of the background research of the research plan in the beginning of its solving. The partial tasks’ solution supports the fulfilling of the main objectives of the research plan, which are the elaboration and the application of the following methodologies:

- Evaluation of the level of degradation of constructional materials’ mechanical properties, especially the correlation of the results of destructive and non-destructive experimental procedures.
- Evaluation of the degree of damage of structures and structural elements due to various service conditions.

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<sup>1</sup> Dr. Ing. Pavel Polach; Section of Materials and Mechanical Engineering Research, ŠKODA VÝZKUM s.r.o.; Tyllova 1/57, 31600 Plzeň, Czech Republic; pavel.polach@skodavyzkum.cz

- Prediction of negative phenomena of degradation processes occurring in the structure of material, which the structures or the structural elements are made of.
- Evaluation of residual lifetime of the structures and the structural elements.

In the following chapters the definition of the subject of the partial tasks solved in the years 2009 and 2010 of the research plan is mentioned in brief. The partial tasks are included in more general units (corresponding with the titles of the chapters) according to the organizational structure of the ŠKODA VÝZKUM s.r.o. in the research departments or the testing laboratories. The partial tasks given in Chapter 2 are largely solved in the Laboratory of Metallography, in Chapter 3 in the Mechanical Testing Laboratory, in Chapter 4 in the Dynamic Testing Laboratory, in Chapter 5 in the Laboratory of Noise and Vibration, in Chapter 6 in the Thermal Spraying Department, in Chapter 7 in the Laboratory of Analytical Chemistry and in Chapters 8 and 9 in the Computer Modelling Department.

## **2. Structural aspects of degradation of materials of power plant equipment**

The partial tasks are especially aimed at materials the power plant equipment parts. Their subject is monitoring and evaluating the degradation processes and the verification of new materials of better resistance to the individual degradation processes. Attention is especially paid to the creep loading but the influence of corrosion, fatigue damage and embrittlement is monitored as well.

### *2.1. Database of superficial defects detected using an endoscope*

The aim of the partial task is creating the database of defect detections determined by means of endoscope inspections of the power plant equipment's parts and to correlate them with the data acquired using other non-destructive methods and possibly even using destructive tests.

### *2.2. Study of materials degradation using the electrochemical methods*

In the framework of the partial task the advanced portable electrochemical apparatus was developed and verified to evaluate the degradation of material properties of power plants equipment caused by a long-time service. The aim of the partial task is the determination of electrochemical characteristics of the used materials and the correlation of those values with other data that characterize the material degradation (i.e. with the changes in mechanical properties, with the development of microstructure and submicrostructure, etc.).

### *2.3. Development of the microstructure of the advanced steels' welded joints under creep loading*

The aim of the partial task is to determine the principle of the creep strength and the microstructure stability of welded joints of the advanced materials which are used for producing the steam turbines parts [5]. The results serve for the selection of the most suitable combinations of materials and technological processes at turbines production, which ensure the required parameters for the selected parts and nodes.

#### *2.4. Electrochemical potentiokinetic reactivation measurement to determine the stainless steels sensitization in a non-destructive method*

The aim of the partial task is to master the method of the electrochemical potentiokinetic measurement with a double loop (DL EPR) in order to assess the degree of sensitization of stainless steels and alloys. The portable measurement cells intended for the operational measurements are developed and verified. The measurement results are correlated with the sensitization characteristics, measured on the basis of chemical exposition tests, and with the material microstructure.

#### *2.5. Study and verification of new progressive ultrasound methods aimed at the residual stress measurement*

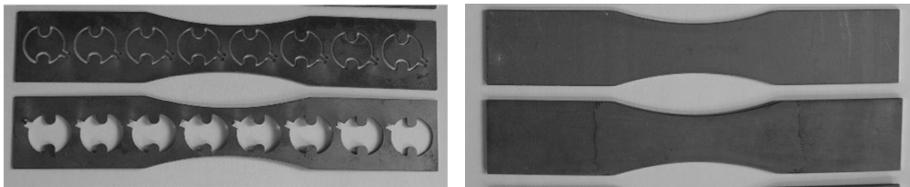
The aim of the task is to modify progressive ultrasound methods of non-destructive testing in such a way that they should be usable for detecting defects and material constants and consequently for determining the magnitude and direction of the surface stress – residual stress – in the loaded components of power plants' equipment. The advantage consists especially in the possibility of the measurement of residual stresses applying „in-situ“ method, which enables to define the stress state in the given point of the structural component more precisely.

### **3. Assessment of degradation processes of constructional materials for the purposes of residual lifetime determination of components and structures**

The basic engineering problem of the mechanical properties degradation due to external factors is the deterioration of materials' and structures' resistance to the brittle fracture failure. In some cases, an inevitable deterioration of mechanical properties of structural parts owing to their utilization in the particular structure is concerned (multiaxial stress, constructionally inevitable notches, welded joints, etc.). Other cases of “classical” degradation are caused by a long-time acting of external influences or service conditions (high temperature, cyclic loading, corrosion and their combinations).

#### *3.1. Development of the methodology of measuring the mechanical properties of metals using classical and miniature test specimens*

The aim of the partial task is to get acquainted with the methods of measuring the basic mechanical properties of constructional materials exposed to fatigue and creep loading and to determine their resistance to the brittle fracture failure on small test specimens (see Fig. 1 for illustration).



**Fig. 1.** Small tests specimens and classical test specimens for fatigue tests.

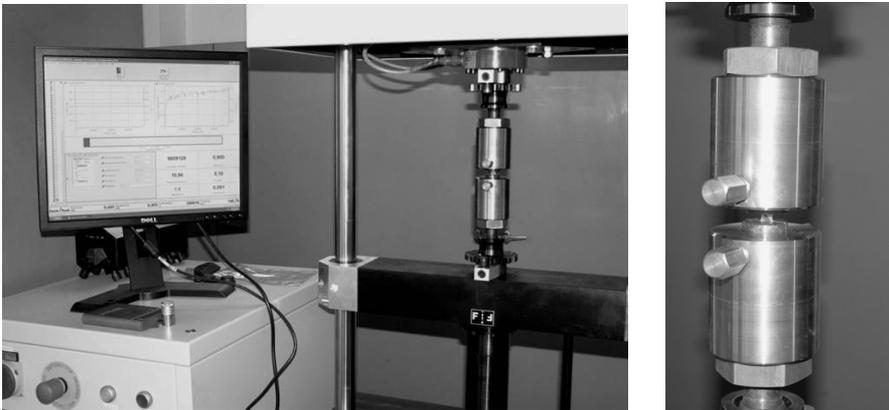
The testing of mechanical properties of constructional materials by means of tests on small test specimens is important in many practical cases, in which it is not possible to take sufficient amount of representative sample of the material from the structural element for the manufacturing of the classical test specimens.

### *3.2. Evaluation of constructional materials degradation and of residual life of the selected degraded components*

The aim of the partial task is to elaborate the methodologies of the evaluation of degradation of mechanical properties of the constructional materials used in power and transport engineering. The properties of materials degraded in service under creep conditions and fatigue loading are investigated [6].

### *3.3. Fatigue tests on the small test specimens and evaluation of the test results*

The aim of the partial task is to master the measurements of fatigue characteristics on the small test specimens (see Fig. 2), their correlation with the results obtained on the classical testing specimens and further making use of the small test specimens in the evaluation of degradation of materials under a long time cyclic loading.



**Fig. 2.** Workplace for fatigue testing on small test specimens and the jaws detail.

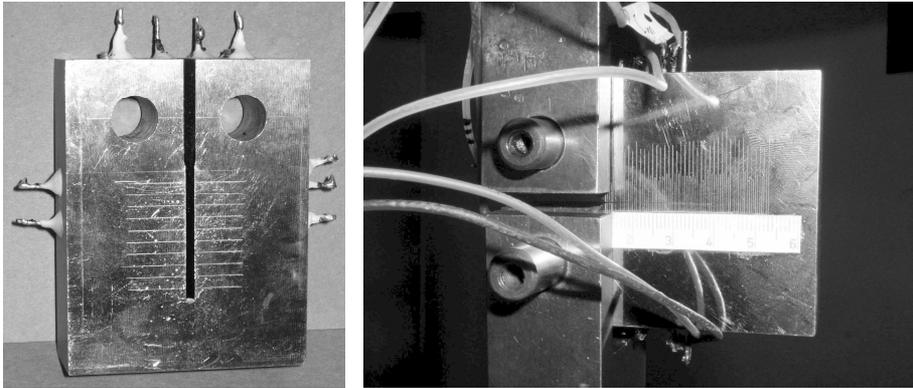
## **4. Degradation of materials and structural nodes under the operational dynamic loading**

Partial tasks in this area are aimed at engineering constructions under loading with time variable forces. Attention is focused on the impact of the material degradation on the structures and their parts, especially welded joints, and the influence on the service life.

### *4.1. Prediction of the service reliability of constructional parts exposed to the cyclic loading*

The partial task is focused on the development of the methods of cyclic laboratory tests of machine parts and on the laboratory tests of constructional nodes. Both the methods of low-cycle and high-cycle fatigue tests of materials at low and high

temperatures and the software for their evaluation are developed [7]. The application of the potential method on the WOL test specimen is given in Fig. 3 for illustration.



**Fig. 3.** The simulation of crack in the WOL test specimen and WOL test specimen in loading device.

#### *4.2. Development and verification of a portable measuring system*

In order to estimate the residual life of the constructional part based on fatigue damage it is necessary to know the history of the stress in the part in the course of the substantial service time. Stress in the constructional elements can be monitored by a portable unmanned measuring system, which samples continuously mechanical stresses (and possibly even other quantities), performs the necessary on-line data processing and stores the measured values in memory for further processing. The measuring system was verified during a both laboratory and service measurement.

#### *4.3. Development of the database for evaluating the fatigue tests*

In the framework of the partial task the records of all the registered fatigue tests performed in ŠKODA VÝZKUM s.r.o. during the last years were collected. The IBM Lotus Notes software is used to administrate the created database.

### **5. Development of the fatigue tests methods for the application to moving blades of rotating machines**

#### *5.1. Testing of the moving blades of rotating machines*

The partial task is solved in the workplace for fatigue testing of rotating machines blades, which is provided with the furnace for testing under higher temperatures. The aim of the partial task is to carry out and evaluate the fatigue tests performed on the sets of the moving blades and the assessment of the blades material degradation.

### **6. The influence of the thermally sprayed coatings on the changes in the functional properties of the coated parts**

Thermal spraying enables to adapt optimally the surface properties of the elements to the service conditions, which prolongs their lifetime and improves reliability and

safety of the whole structure. Suitable choice of material and preparation of the technology of thermal spraying for the individual applications is dependent on the coatings properties knowledge, on the basis of which it is also possible to predict the coatings lifetime under various modes of loading.

#### *6.1. Development of the methodologies for evaluating the properties of the wear resistant coatings*

The aim of the partial task is to elaborate the methodologies for the evaluation of surface properties of the thermally sprayed parts considering their resistance to mechanical damage caused by various types of wear. The solution can be found in the existing methods of surface properties evaluation (hardness, microhardness, resistance to abrasive, adhesive and erosion wear, etc.), which are adapted to the requirements of thermal spraying following from their specific microstructure [8].

#### *6.2. Development of the methodologies for the characterization of the thermally sprayed coatings properties in the coating-substrate interface*

The aim of the partial task is to develop the methodologies for the evaluation of properties of the thermally sprayed coatings in the coating-substrate interface. The identification and evaluation of the influences acting on the properties of the coating-substrate interface is an important contribution for understanding the principle of the bond strength of thermally sprayed coatings to the substrate. At the same time developing and applying the methodologies for the bond strength evaluation contribute to improving in the reliability of coatings in industrial practice.

#### *6.3. Development of the methodologies utilizing the indentation technique for the characterization of the thermally sprayed coatings*

The task deals with developing the methodologies of the evaluation of fracture toughness of thermally sprayed coatings' properties. The aim is to replace demanding classical methods of fractures initiation in the coatings with indentation methods enabling the properties' evaluation in micro volumes. Important factors and their relations influencing the results obtained applying the indentation methods are identified and evaluated, general formal models' validity on the thermally sprayed coatings on the base of composites and other materials are verified. The methodology development enables to include the fracture characteristics into the more precise formal models in the field of the thermally sprayed coatings wear in dependence on the stress conditions.

### **7. The preservative agents' degradation study**

#### *7.1. Study of the degradation of preservative agents on metal materials used in power engineering at a long-time storing in maritime localities*

The aim of the partial task is to evaluate the degradation of preservative agents used in power engineering in dependence on their exposure in a tropical chamber. The tests are performed on the P92 steel specimens protected with preservative agents. After the expiration of the exposure in the tropical chamber the state of the preservative agents was evaluated applying the method of the infrared spectrometry.

## **8. Processes and methods of the evaluation of the material degradation impact on its fatigue properties**

The applying of computer simulations enables to predict the critical points of the structures and to estimate their operational strength and fatigue life. The aim of the partial tasks is to find the approaches to the fatigue life assessment of structures or materials exposed to degradation processes. The FEM stress analysis is used for the fatigue life assessment.

### *8.1. Determination of strength and lifetime of welded steel constructions*

In the first stage of solving the partial task it was necessary to find and purchase a suitable commercial fatigue postprocessor. Further step was a study of theories implemented in the post-processor. A background research of the used approaches was carried out in order to get acquainted thoroughly with the methods of evaluating a strength and fatigue life of welded joints. Individual types of tasks are verified on the chosen examples from practice, if possible. The programming and testing of the chosen methods enable to know them deeper and to compare them mutually [9].

### *8.2. Study of the influence of the welded joints modelling on the deformation resistance of thin-walled steel constructions*

In the welded constructions degradation of the material properties occurs due to acting high temperatures in the welded joints areas. In case the constructions are exposed to acting the extreme loadings (impacts and other breakdown states), during which their plastic deformation occurs, the thermally affected joints areas can behave in a different way than the basic material. The aim of the partial task is to determine the optimum approach to modelling the welded joints in FEM software for rapid dynamic processes in connection with large deformations and the evaluation of the necessity of the welded joints modelling in the thin-walled constructions which are exposed to loading causing large deformations.

### *8.3. Study of the theory and assessment of the fatigue life at higher temperatures*

The present state of the problems of the thermomechanical fatigue, especially the Sehitoglu model, is studied. The methodology that can be used for defining the parameters of the Sehitoglu model or possibly some of its modified versions should be the output. This methodology is dependent on the type of experimental data being at disposal. The aim is to enable to estimate the thermomechanical damage on the basis of available and commonly performed experimental measurements.

## **9. Application of multibody simulations in the field of transport and power engineering**

### *9.1. Applying multibody simulations in the field of transport and power engineering*

Attention is focused on the development of existing approaches to multibody models creation and to searching new possibilities of the simulations results' application to the evaluation of reliability, safety and lifetime of structures and their parts. The multibody simulations' results are usually verified with the records of service measurements on the real structures.

## 10. Conclusion

The results of a six-year solving of the research plan are presented in 145 titles of ŠKODA VÝZKUM s.r.o. research reports. So far 26 papers have been published in scientific journals, 105 ones in conference proceedings, 9 chapters have been published in books and 43 other outputs have been realized (e.g. introduction of a new methodology, etc.). The overview of the process of solving the research plan and of the achieved results is given especially in the research reports, e.g. [2-4].

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