FAILURE ANALYSIS AND PREVENTION IN CHINA

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The paper reviews the National Conferences on Failure Analysis of Machines and Equipment in China organized by CMES. Some of the fracture problems related to pressure vessels, power stations, jet engines, ground vehicles and railway system are surveyed. Theoretical research in the field is also briefly presented.

INTRODUCTION

The Chinese Mechanical Engineering Society (CMES) and the Ministry of Machine-Building make every effort to stimulate the failure analysis and prevention in the whole country. "Learning from failure", it is often highlighted that the failure analysis is an important means to improve products quality, service life and safety reliability. The First National Conference on Failure Analysis of Machines and Equipment was held by CMES in 1980 and more than 310 case histories were collected. The Second National Conference was held in 1984 and the conference proceedings of 100 selected papers with 1309 photos were published. The Third National Conference, whose scale is estimated to have more than 350 participants, will be held in May of 1988. The contents of three Conferences is shown in TABLE 1. Besides, a series of conferences on failure analysis in special field, e.g. failure analysis of components and structures in power stations, were held during past

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TABLE 1-Contents of Three National Conferences

Subject	1st Conf No. of papers	%	2nd Conf No. of papers	%	3rd Conf No. of papers	%
Power Station	33	10.6	15	8.0	23	7.5
Pressure Vessel	42	13.5	11	5.9	21	6.9
Pipe	27	8.7	11	5.9	18	5.9
Shaft, Rod	67	21.5	16	8.5	57	18.7
Wheel, Gear	32	10.3	19	10.1	28	9.2
Bolt, Spring, Bearing	48	15.4	27	14.4	77	25.2
Theory, Method	33	10.6	28	14.9	54	17.7
Other	29	9.3	61	32.4	27	8.9

decade. In addition, the National Conferences on Fracture and the National Conferences on Fatigue are organized every 3 to 4 years for each alternately.

PRESSURE VESSELS

Two of the largest spherical vessels in China for storage of natural gas have been built recently. The dimensions are 26.74 m in inside diameter, 1011 m^3 in volume , and 34 mm in wall thickness. The operating pressure is 0.8 MPa, test pressure is 1.1 MPa, and the total length of weld is 1340 and 1270 m respectively. At the begining of 1987, a pressure shell for 5 MW nuclear reactor was built. Its diameter is 1800 mm, its height is 6600 mm, and design pressure is 3 MPa. Another 3200 X25700X200 mm high temperature-pressure hydrogenation reactor vessel weighted 560 tons is planned to be constructed. Its design pressure is 19.5 MPa, and design temperature is 427°C. The vessel will be made of 2¼Cr-1Mo steel and 347 steel.

It is estimated that there are more than 310 thousand boilers and 11.5 million different type pressure vessels in service in China. Securing safety of boilers and pressure vessels is of vital importance. Statistical data showed that 1324 cases of explosion failure occured during the period from 1979 to 1983 and some of them brought catastrophic results.

In order to prevent failure, it is required to establish an acceptance standard for defects. On the bases of tremendous experimental results, a code of defects assessment for pressure vessels(CVDA-84) was adopted. Twenty universities and research institutes were involved in this task and near 200 scientists and engineers made contribution to this code. CVDA-84 code elucidates the comprehensive assessments for brittle fracture, fatigue, leakage, collapse, stress corrosion, corrosion fatigue, creep and creep-fatigue. This code also assimilates whatever is benificial in similar documents such as codes of ASME, WI, CEGB etc.

Another example of failure prevention is the work done for domestic liquidized gas steel bottles by Zhong (1). The total number of this kind steel bottles is more than 8 million. Normally its operating pressure is less than 0.6 MPa, design pressure is 1.6 MPa, and Proof test pressure is higher than 8 MPa, so in general it is quite safe. Two criteria approach and failure assessment diagram developed by Dowling and Townley(2) was used to evaluate the safety of the steel bottles. The results showed the tolerance of crack size is 0.90 mm in depth, and this was confirmed by burst tests of steel bottles with artificial cracks.(see Fig.1)

POWER GENERATION

In the past two years, the annual increase in the newly installed electricity-generating equipment reached 8 million kilowatts. However, some premature failures of thermal and hydro electricity plants still occured. A catastrophic failure as the steam turbine disc failure at Hinkley Point "A" in U.K. happened in 1965. Until September 1981, cracking was found on 51 discs.

A typical examples(3) of crack analysis and life prediction is shown in Fig.2. The turbine disc was made of 34CrNi3Mo steel with K_{1c}=115-148 MPa$\sqrt{m}$. The crack growth rate due to stress corrosion under environment of 3%NaCl +1%Na_2SO_4 at 80°C is about 1.25 mm/year. The critical crack length of 14th disc of Aπ-25-2 type turbine is 32 mm and the residual life from detection of 3 mm crack is about 11.5 years.

Since then 9 rotors have been retired. And from now on the design routine of turbine should consist of conventional structural strength design, fracture resistance design and stress corrosion resistance design.

A defect assessment of a hydrautic turbine shaft was performed by Gao(4). The shaft was composed of a cylindric section and two flanges by welding. NDT detected a weld defect(lack of fusion) 320 mm long and 3-25 mm wide . The construction of the shaft is shown in Fig. 3,a. The shaft was made of 20MnSi steel. The mechanical properties of weld metal are: K_{Ic} =141.5 MPa$\sqrt{m}$, ΔK_{th}=6.3-11.1MPa$\sqrt{m}$, the Paris' constants n=3.36, C=4.07X10^{-11}. The shaft subjected to torque 1100 ton-m, load of weight 175 tons and water force 600 tons. The effective stress intensity of I-II mixed through crack was calculated and mechanical model of K calculation is shown in Fig.4 b. The results indicated that in the most dangerous case, the effective stress intensity K*=9 MPa$\sqrt{m}$, i.e. $K^* \ll K_{1c}$, so fast fracture can be avoided. But the effective stress intensity range ΔK*=8.8 MPa$\sqrt{m}$, probably greater than the fatigue threshold, so it is possible that the defect will grow during service; even so, the extention of crack is less than 1 mm within 100 years. Specimens cut from the same material and subjected the same ΔK* were tested under tension-torsion combined load, and the results of experiment were fairly coincident with calculated results.

JET ENGINES

Gas turbine disc represents major component in modern aero-engines. In recent years, a "defect tolerant" approach to predict the fatigue life of jet engine components has been developed. It is important to know the fatigue performance of superalloys under the condition approaching to practical service.

A ferro-base superalloy GH36(C 0.38%, Cr 12.5%, Mo 1.25%, Ni 8.0%, Mn 8.5%, Nb 0.35%, V 1.4%, Fe balance) was used to investigate the low cycle fatigue life distribution at 550°C.(5) The histograms of the fatigue data exhibited apparent double peaks. The distribution patterns on Weibull probability paper is shown in Fig.4. It is obvious that the data points are separated into two segments. SEM examination revealed that intergranular dimples and intergranular cracking rather than striation were more developed in the specimens of short life.

The conjoint action of the high cycle fatigue (or minor cycle) and the low cycle fatigue (or major cycle) in GH36 was also investigated.(6) The amplitude ratio is defined as $m=\frac{1}{2}\cdot K_{minor}/K_{major}$. The da/dn- K_{total} curves with R=0.1 and m=0.0, 0.08, 0.12 are shown in Fig.5. It should be noted, that under ΔK_{total}=20 MPa$\sqrt{m}$, the da/dn at m=0.12 is 20 times as high as that at m=0.

GROUND VEHICLES AND RAILWAY SYSTEM

The motor vehicle industry in China consumes 1.8 million tons steel and 0.4 million tons cast iron per year. The lifetime of a ground vehicle is limited by fatigue, corrosion, wear and their combined effects. In order to meet the demands for lighter, more efficient and durable vehicles, appropriate fatigue design is required. The methodology in fatigue design can be divided into four categories: based on S-N curve, based on fatigue crack initiation and propagation, based on damage accumulation and based on reliability.

Concerning reliability, fatigue may be considered as a Markov process consisted of initial state, cracked-body state, fractured state, as well as crack initiation and crack propagation.(Fig.6) In fatigue life calculation, it is needed to calculate the probability of transition μ_{1-2} and μ_{2-3}. $\mu_{1-2}$is the probability of fatigue crack nucleation, which can be calculated using "local stress-strain" approach. μ_{2-3} is the probability of trasition from crack-initiated body to fractured state. This problem can be resolved using the concept of probability fracture mechanics.

Fracture and fatigue of axles, beams, carwheels and rails did exist and caused loss of life and economy. Especially in Northeast and Northwest of China, the temperature in winter may be down to -20°- -54°C. Usually the existing fatigue cracks result in brittle fracture in winter. In these circumstances, the compromise of strength and fracture toughness of materials is very important. Surface cold rolling at the shoulder of axle can effectively raise its fatigue limit without increasing ductile-brittle trasition temperature. Spray quenching on rail can markedly increase wear resistance and fatigue limit, but decrease fatigue threshold. Although the fatigue problem of axle was recognized by the mid-nineteenth century, further investigation is still needed to prevent fatigue failure in transport system.

THEORETICAL RESEARCH

In order to avoid failure, it is prerequisitic to learn how failure occurs. The research on mechanisms of different types of fracture, especially fracture under severe service conditions, including stress corrosion, corrosion fatigue, hydrogen cracking, fatigue at high temperature, fracture at low temperature etc., is supported by National Natural Science Foundation of China. Fracture is an interdisciplinary field and it needs combination of solid mechanics and materials science in research work. A long term research program titled " The relation between microstructure and mechanical behaviour of materials" has been being supported by NNSF. A new branch called as " Microstructural fracture mechanics" has been exploited, and finite element method is employed in the area down to 5 μm, as a result it enables fracture toughness, fatigue threshold and Bauschinger effect of engineering materials to be elucidated by means of the parameters of microstructure and mechanisms.

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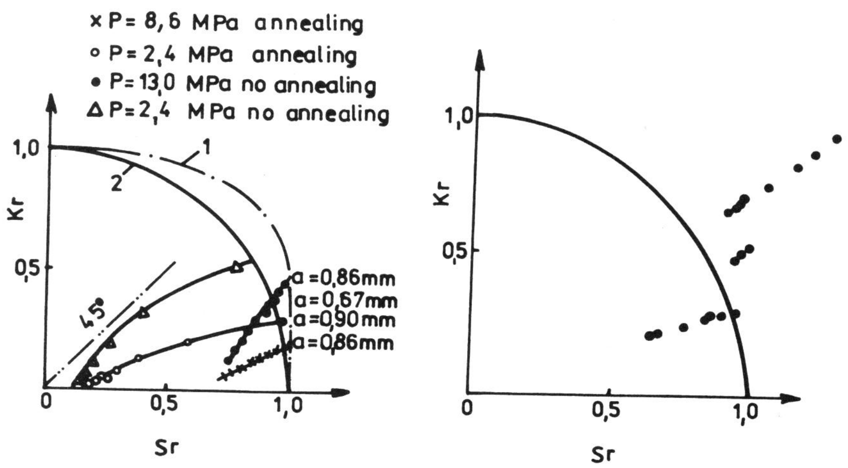

Figure 1 Failure assessment diagram for liquidized gas steel bottles

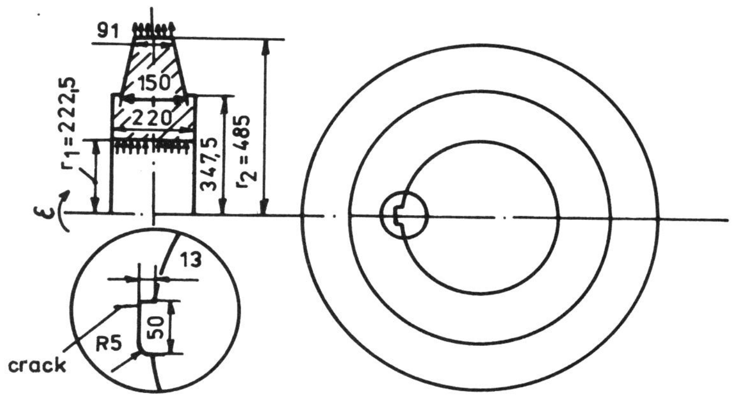

Figure 2 Cracking of a steam turbine disk

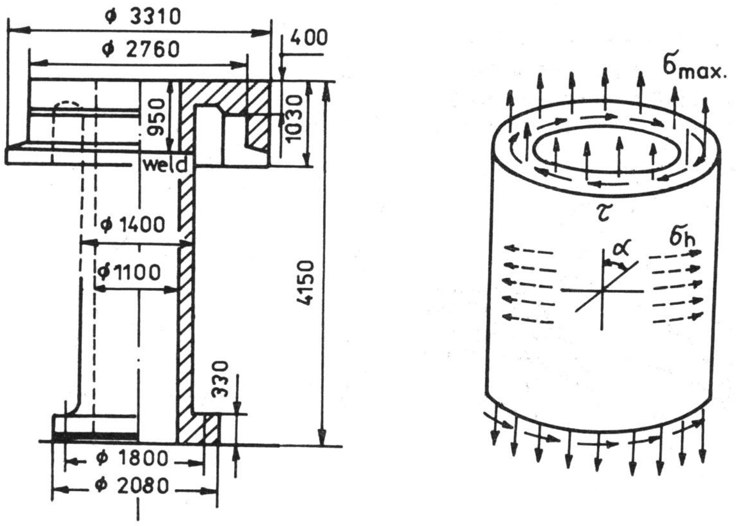

Figure 3 A hydraulic turbine shaft and its mechanical model

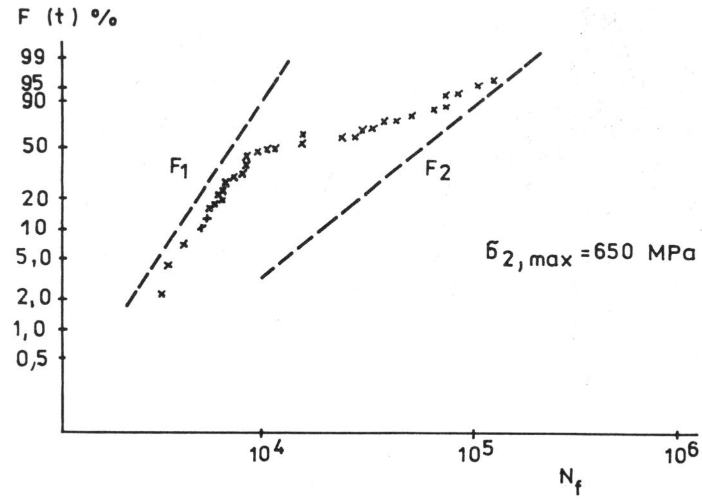

Figure 4 High temperature fatigue life distribution of superalloy GH36

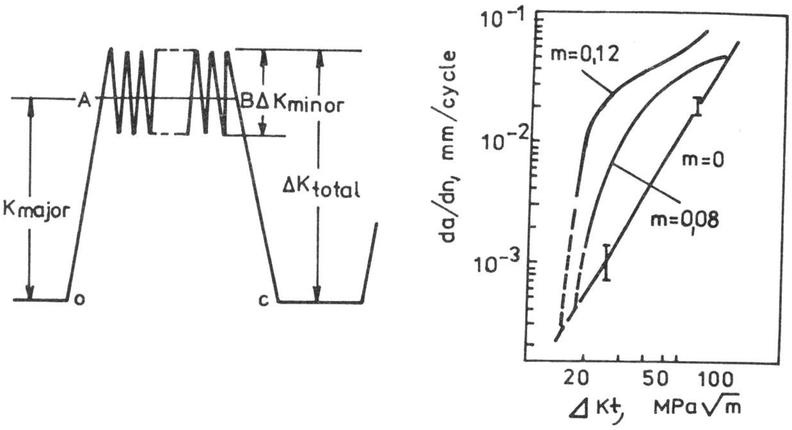

Figure 5 Conjoint action of HCF and LCF in GH36

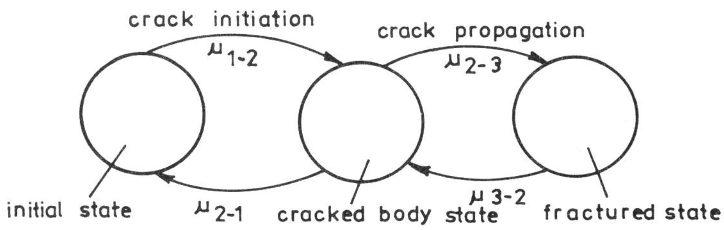

Figure 6 Fatigue considered as a Markov process