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Failure analysis of a pull rod actuator of an ATOX raw mill used in the cement production process

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ABSTRACT

A failure analysis of a forged and machined pull rod made of a quenched and tempered high strength steel – namely DIN 34CrNiMo6 – is presented in this paper. The pull rod under study is one of the three rods that connect the three existing hydraulic cylinders to the roller mill and it is used to exert grinding pressure on the roller in an ATOX raw mill. The study of the failure involved the mechanical system's simulation, as well as the fatigue damage assessment based on the application of the Rainflow Method and Fracture Mechanics principles. The pull rod's stress state was determined from *in situ* strain gages rosettes measurements, and system's simulation showed that the pull rod was designed to support axial loadings only. To ensure this stress state, a proper functioning of the plain bearings and a good condition of the elastomers of the horizontal rod buffer are required. According to the stress-life approach given in the FKM guideline, the current design solution should provide a useful life of 50 years to the pull rod. However, fatigue crack growth calculations made with the strain spectra registered demonstrated that the presence of an initial surface crack is extremely harsh to the lifespan of the rod, which will reach a critical value in a much shorter period of time. Surface finish, corrosion protection and maintenance actions to ensure the correct functioning of the plain bearings, could be important to ensure the desired longevity of the pull rod.

1. Introduction

The main goal of the work herein presented was to analyse a mechanical failure that occurred on a pull rod of an ATOX raw mill. The ATOX raw mill under study is shown in Fig. 1a and b, in which are represented the most important components of the raw mill, as well as the recurrent location of failure of the pull rod. The ATOX raw mill is used to prepare kiln feed for the production of cement clinker, and it is one of the most important equipments in the production process of cement, whereby a failure could have a negative impact in the production process and, consequently, in the incomes of the enterprise. The ATOX raw mill uses compression and shear generated between the rollers and the rotating table to crush and grind raw materials (Fig. 1b). The raw materials are directly feed onto the grinding table by the feed chute (Fig. 1b) and the rotation of the grinding table brings the materials towards the grinding track and under the rollers. The three rollers, each one weighting about 50 ton, are kept centred on the grinding table by a triangular structure and by three horizontal rods that are connected to the mill body in order to

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Nomenclature

$2N$	number of reversals
a	crack length
a_o	initial crack length
a_f	critical crack length
C_D	size correction factor
$C_{D,FKM}$	size correction factor according to FKM-Guideline
C_L	load correction factor
C_R	reliability correction factor
$C_{R,FKM}$	reliability correction factor according to FKM-Guideline
C_T	temperature correction factor
$C_{E,T,FKM}$	temperature correction factor for the endurance limit according to FKM-Guideline
$C_{\sigma,R}$	roughness correction factor for normal stress
$C_{\sigma,R,FKM}$	roughness correction factor for normal stress according to FKM-Guideline
$C_{\sigma,E}$	endurance limit factor for normal stress
$C_{\sigma,E,FKM}$	endurance limit factor for normal stress according to FKM-Guideline
C, m	coefficient and exponent of the Paris law, respectively
$\frac{da}{dN}$	crack growth rate
E_{RT}	elastic modulus at room temperature
E_{ET}	elastic modulus at elevated temperature
f_w	finite width correction factor
$G_{k,\sigma}$	relative normal stress gradient
K	stress intensity factor
K_f	fatigue notch factor
K_m	stress intensity factor due to misalignment
K_t	stress correction factor
K_t	elastic stress concentration factor
K_{tb}	bending stress concentration factor
K_{tm}	membrane stress concentration factor
Y	fracture mechanics geometric factor
$M_{m,t,tb,tm}$	stress intensity magnification factors
M_σ	mean stress sensitivity factor in normal stress
N_E	endurance cycle limit
$n_{k,\sigma}$	supporting factor
R	stress ratio
S	applied stress
S_a	stress amplitude
S_{ar}	equivalent fully reversed normal stress amplitude
S_e	corrected endurance limit of a notched rod-shaped component under fully reversed loading
S_f	fatigue strength coefficient
S_m	normal mean stress in a stress cycle
S_{min}	normal minimum stress in a stress cycle
S_{max}	normal maximum stress in a stress cycle
ε	strain
ν	Poisson's ratio
σ_1	maximum principal stress
σ_2	minimum principal stress
φ	direction of maximum principal stress
ΔS	applied stress range
ΔS_b	bending stress range
ΔS_m	membrane stress range

prevent the roller's rotation (Fig. 1b, c). The grinding compression is axially applied by three pull rods, each of which is attached to the roller shaft at one end side (Fig. 1b, c, d) and to a hydraulic cylinder at the opposite side (Fig. 1c) [1].

The ATOX raw mill entered in service in the 80s of the 20th century and since then maintenance has been periodically carried out. The analysis of the most recent failures registered allowed to conclude that the pull rod failed four times between 2014 and

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