Engineering Failure Analysis 86 (2018) 131–141

Contents lists available at ScienceDirect

Engineering Failure Analysis

journal homepage: www.elsevier.com/locate/engfailanal

Delamination failure monitoring of plasma sprayed composite ceramic coatings in rolling contact by acoustic emission

Jia-jie Kang[a,b,c,*], Bin-shi Xu[d], Hai-dou Wang[a,d,**], Cheng-biao Wang[a,b,c], Li-na Zhu[a,b,c]

[a] School of Engineering and Technology, China University of Geosciences, Beijing 100083, China
[b] National International Joint Research Center of Deep Geodrilling Equipment, Beijing 100083, China
[c] Key Laboratory of Deep Geodrilling Technology, Ministry of Land and Resources, Beijing 100083, China
[d] National Key Lab for Remanufacturing, Academy of Armored Forces Engineering, Beijing 100072, China

ARTICLE INFO

Keywords:
Delamination
Rolling contact fatigue
Composite ceramic coating
Acoustic emission

ABSTRACT

The aim of present study is to monitor the delamination failure of plasma sprayed Al_2O_3–40 wt% TiO_2 composite ceramic coating (AT40 coating) in rolling contact condition by acoustic emission (AE) technology. The AE signals of the delamination failure process were divided into three types (type I: normal contact; type II: fatigue crack initiation; type III: delamination failure) based on the feature of AE count. The waveforms and frequency spectrums of different types of AE signals during delamination failure process of the coatings were obtained by Empirical mode decomposition (EMD) method. The relationship between the waveform/frequency of the AE signals and the delamination failure mechanism of the AT40 coatings were discussed in detail.

1. Introduction

Advanced surface engineering technologies such as laser cladding [1,2], plasma cladding [3], thermal spraying [4,5], and chemical heat treatment [6] are widely used for improving the surface properties which including wear-resistance [7], anti-corrosion property, high-temperature resistance of the mechanical components. Al_2O_3 with high hardness and wear-resistance is a typical ceramic material which can be deposited on the steel substrate by using plasma spray technology for its high flame temperature and high melted particles flying velocity. Furthermore, the addition of TiO_2 with the content of 40 wt% into Al_2O_3 could significantly improve the fracture toughness, cohesive strength, and bonding strength of the plasma sprayed coatings. However, when the mechanical components coated with Al_2O_3–40 wt% TiO_2 composite ceramic coating (AT40 coating) serviced in rolling contact condition, such as shafts, cams, and gears, rolling contact fatigue (RCF) failure tend to occur under the effect of shear stresses within the coating-substrate system. According to the former RCF investigation of metal coating (e.g. FeCrBSi alloy coating [8]), ceramic coating (e.g. Al_2O_3–2.3 mass% TiO_2 coating [9]), and cermet coating (e.g. WC-Co coating [10,11], CrC-NiCr coating [12,13]), the RCF failure had been divided into three typical modes, namely surface abrasion, spalling, and delamination. It is generally recognized that delamination is the severest failure mode of the coatings during RCF process attributed to its large material removal area and sudden occurrence. As well as the RCF lives of the failed coating samples with the mode of delamination were much shorter than those of the failed coating samples with the mode of surface abrasion and spalling [14].

In order to analyze the RCF failure mechanism of the coatings, the test should stop immediately once the RCF failure occurs.

* Correspondence to: J.J. Kang, School of Engineering and Technology, China University of Geosciences, Beijing 100083, China.
** Correspondence to: H.D. Wang, National Key Lab for Remanufacturing, Academy of Armored Forces Engineering, Beijing 100072, China.
E-mail addresses: kangjiajie@cugb.edu.cn (J.-j. Kang), wanghaidou@tsinghua.org.cn (H.-d. Wang).

https://doi.org/10.1016/j.engfailanal.2018.01.005
Received 15 September 2017; Received in revised form 8 January 2018; Accepted 21 January 2018
1350-6307/

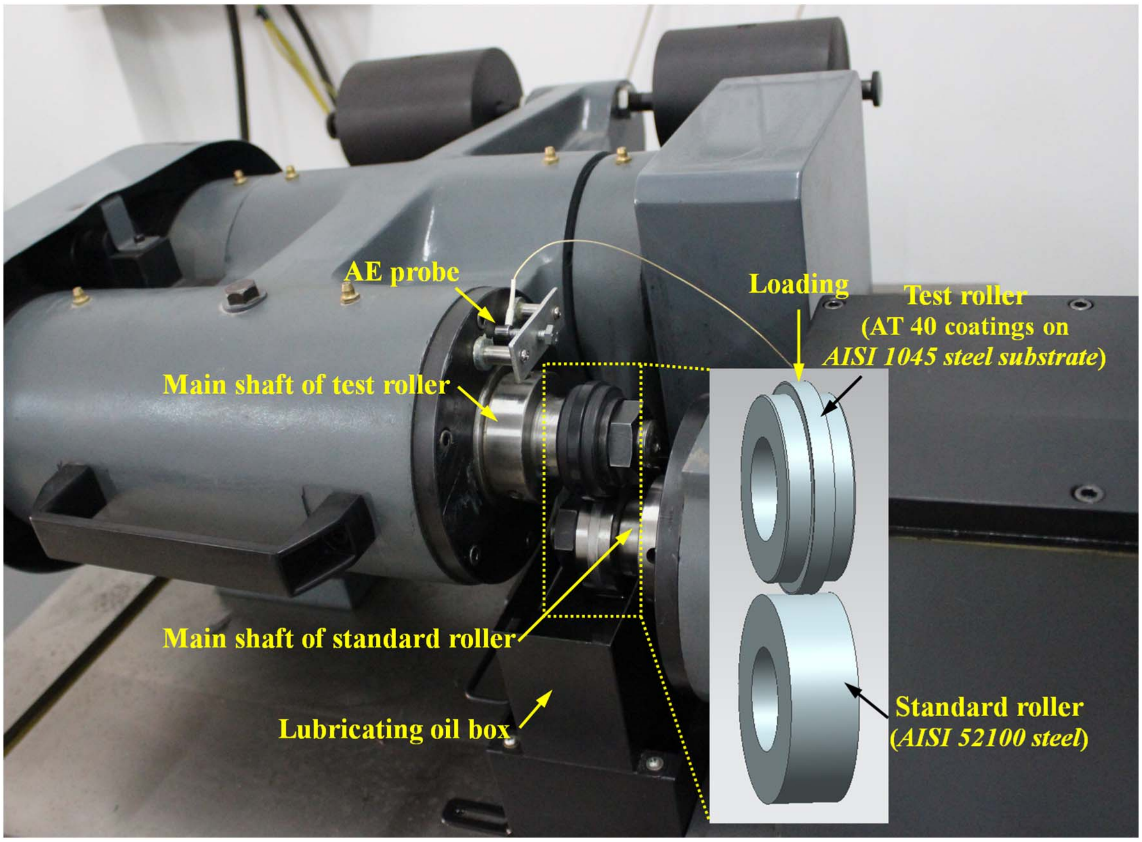

Fig. 1. Schematic of the test roller and standard roller.

Traditionally, accelerometer and fast Fourier transformation of the vibration signal were used to monitor the RCF failure of the coating samples especially delamination failure in the earlier research [15]. However, the vibration signals with low frequency are easily to be affected by the environmental noises such as machine noises, so it is difficult to characterize the RCF process by analyzing the vibration signals. Acoustic emission (AE) phenomenon which defined as the transient elastic waves generated from a rapid release of strain energy caused by the material deformation under the effect of load can be used for monitoring the failure process of coating materials under loads [16]. Piao Z.Y. et al. found that AE signal parameters (energy and amplitude) are sensitive to the initiations and propagations of the fatigue cracks within the Fe-Cr alloy coating [17]. Zhang Z.Q. and Li G.L. compared the response of vibration signals and AE signals during the RCF process of Fe-based alloy coatings and found that the AE method can monitor the whole RCF failure process which includes elastic and plastic deformation; initiation, propagation and closure of the fatigue; as well as fracture of the coating material, while the vibration analysis can only detect the final fatigue [18,19]. Rahman Z. et al. revealed that AE hit counts rate is an important parameter to reflect the incipient damage during the RCF process of steel rollers [20]. Some characteristic parameters of AE signals such as energy, amplitude, and AE hit counts rate were confirmed to be used to monitor the RCF failure process of the coatings and to identify the stages of the failure process. However, the judgment of the failure modes especially delamination failure which is the severest failure mode during the RCF process of the coatings was not accurate enough. Analyzing the waveforms and frequency spectrums of the AE signals which include lots of useful information is a feasible approach to characterize the delamination failure of the coatings.

In the present research, AE technology was used to monitor the RCF failure process of the plasma sprayed AT40 coatings, the waveforms and frequency spectrums of the AE signals corresponding to the delamination failure were analyzed based on the Empirical mode decomposition (EMD) method.

2. Experimental test procedure

2.1. Coating deposition

The tempered AISI 1045 steel substrate rollers were blasted and preheated to the temperature of 200 °C. The Ni/Al bonding coatings and AT40 composite ceramic coatings were prepared on the substrate rollers by using supersonic plasma spray technology. The spraying parameters of Ni/Al coatings were as follows: argon gas flow 3.4 m^3/h, hydrogen gas flow 0.3 m^3/h, nitrogen gas flow 0.6 m^3/h, spraying current 320 A, spraying voltage 140 V, spraying distance 150 mm, powder feed rate 30 g/min; and those of