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Fatigue resistance of plasma-sprayed CrC–NiCr cermet coatings in rolling contact

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Abstract

The aim of this paper was to address the fatigue behavior and failure modes of plasma-sprayed CrC–NiCr cermet coatings in rolling contact under the identical tribological conditions of contact stress at room temperature. For all tests, the thicknesses of the coatings were controlled to be about 100 μm. Thirteen rolling contact tests were performed to obtain the statistical result. The Weibull distribution plot of fatigue-life data of the coating specimens was obtained. The failure modes and mechanisms of the coatings were studied on the basis of the worn surface observations of the failed coatings. Experiment results showed that the RCF life data of the coatings exhibited high scattering, since the bimodal distribution of the fatigue-life data of the coatings was observed in the Weibull plot. Different failure modes named as spalling and delamination were observed during this investigation. However, the failure modes might be associated with the microstructure and the bonding strength of the coating, and the distribution of shear stress at the subsurface. The coatings failed in the spalling generally exhibited the relatively high fatigue lives and the coatings failed in the delamination exhibited low lives, resulting in the bimodal distribution of the fatigue-life data in the Weibull plot.

Keywords: Rolling contact fatigue; CrC–NiCr cermet coating; Weibull plot; Bimodal distribution; Failure modes

1. Introduction

In many types of industrial applications, such as gears and rolling bearings, surface damage generated owing to the rolling contact limits the useful life of the components and hence reduces durability and product reliability. Rolling contact fatigue (RCF) is defined as cracking and pitting/delamination limited to the near contact surface layer of bodies rolling against each other [1]. Generally, it is believed that the damage due to the rolling contact can initiate either beneath the contact surface (classical subsurface) or at the surface [2,3]. Hence, surface engineering is today becoming an increasingly important discipline to industry to improve the life reliability and load bearing capacity of the components in more hostile environments.

Among the existing techniques used for surface modification, thermal spray coatings deposited by techniques such as plasma spraying (PS), high velocity oxy-fuel, arc wire, etc., can provide a cost-effective solution for tribological applications in pure rolling or rolling/sliding contact. Since it is very important in the evaluation of the safety and life for the components in rolling contact, the fatigue resistance and failure mechanisms of the bulk materials, such as bearing steel, have been addressed in numerous studies by using the experimental or theoretical approach [4–6]. The RCF behavior and mechanisms of the thermal spray coatings in pure rolling or rolling/sliding contacts is, however, not thoroughly understood, which may be due to the nature of the thermal spraying processes [7]. Even using state of the art spraying systems, it is impossible to achieve defect-free sprayed coatings [8]. Generally, because of the nature of the coating process, the microstructure of coatings is often characterized by the lamellar structures (or termed as ''splats'') with the existence of various pores, micro-cracks, splat boundaries, and some unmelted particles. There are different sources resulting in the generation of these defects,

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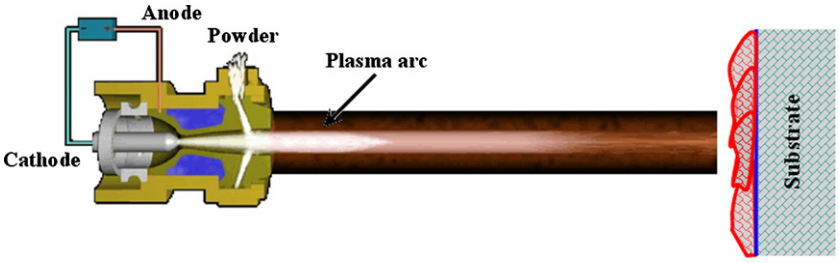

Fig. 1. Schematic of plasma spray torch with a radial powder injection system.

such as the imperfect contact of the splats, the residual stresses due the mismatches of material properties between the coating and the substrate, and the expansion of trapped gases, etc. The existence of these micro-defects may limit the use of the thermal spray coatings to low-stress applications and makes understanding of the RCF failure mechanisms of coatings difficult. Although most of the previous researches concentrated mainly on the failure modes of the coated component under rolling contact conditions [7,9–11], the mechanisms leading to the failures of the coatings have not been fully understood.

WC–Co and CrC–NiCr systems constitute two main carbide materials used in thermal spraying processes in order to improve the wear resistance and decrease the friction coefficient between various sliding components. For the thermal spray coatings investigated under rolling contact conditions, most of the previous work were concentrated on the tungsten carbide based cermet coatings with metallic cobalt binders, e.g., WC–Co, since it is believed that the coatings deposited by using these types of materials have high wear resistance and surface hardness and low coefficient of friction at relatively low temperature (e.g., <500 °C). However, when the service temperature is high, the decarburization of WC into W_2C, W_3C and even metallic W phase leads to the degradation of coating properties and limits the application of these coatings [12]. At elevated temperatures, up to approximately 850 °C, chromium carbide nickel–chromium, i.e., CrC–NiCr, is one of the best coating materials to combat wear owing to its oxidation-resistance [13]. The main shortcoming of CrC–NiCr coatings is a relatively lower hardness than WC–Co system coatings [14]. Up to present, the basic research on the RCF performance of the CrC–NiCr system coatings is seldom found. In such a case, it is necessary to systematically investigate the wear performance and fatigue failure mechanisms of CrC–NiCr coatings under rolling contact conditions.

The aim of this study was to address the RCF behavior and failure mechanisms of the plasma-sprayed CrC–NiCr coatings under the identical tribological conditions of contact stress. One set of fatigue-life data of coatings were characterized by Weibull distribution. The failure modes and related mechanisms of the coatings were investigated on the basis of the surface observations of the failed coating specimens using scanning electron microscope (SEM).

Table 1
Spraying parameters used for preparation of the coatings

Argon gas flow rate	60 l/min
Hydrogen gas flow rate	3.33 l/min
Nitrogen gas flow rate	10 l/min
Spraying voltage	140 V
Spraying current	360 A
Powder feed rate	30 g/min

2. Experimental procedures

2.1. Preparation of coatings

A high-efficiency PS system with a maximum power of 80 kW and a maximum working gas flow of 6 m^3/h was used to deposit the CrC–NiCr coatings. The novel system was composed of plasma torch, power feeder, gas supply, water cooling circulator, control unit with PC interface and power supply unit. The key of this system was a novel supersonic PS gun, as shown in Fig. 1. Compared with the conventional APS, high-efficiency hypersonic PS improved greatly the coatings quality but at low cost [15].

The substrate with ring-type geometry was a commercial middle carbon steel. The thickness, external diameter and internal diameter of the substrate were kept to be 25, 60 and 30 mm, respectively. Prior to spraying, one plane surface of the steel substrate was cleaned in acetone solution and preheated to 100–200 °C, and then sandblasted using corundum powder. In order to achieve good temperature control of the substrate and coating, the substrates were disposed and fixed in the holes on a stainless steel cylindrical holder (SCH), 200 mm in diameter and 4 mm in thickness. The rotation of the SCH was 120 rpm during the spraying. The plasma torch, whose axis was orthogonal to that of the SCH, was translated parallel to the SCH at a constant velocity of 12 mm/s. The spray distance was kept to be 100 mm. The primary gas used in the plasma spraying was argon, with nitrogen and hydrogen as secondary gases. The parameters used for plasma spraying are listed in Table 1.

A commercially available Cr_3C_2–NiCr powder with the nominal composition NiCr-25, CrC-75 (wt.%) was used. The morphology of the powder was given in Fig. 2. After spraying, the thickness of the coating ranged from 300 to 400 μm. The coating specimens were ground and polished to attain a roughness around 0.20 μm at the coating surface. After polishing, for all samples, the coating thickness was about 100 μm.