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Influence of Machine Hammer Peening on the Tribological Behavior and the Residual Stresses of Wear Resistant Thermally Sprayed Coatings

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Abstract

WC-W_2C iron based cermet coatings are widely used in the field of wear protection. In surface engineering, machine hammer peening (MHP) is a novel surface treatment technology, which enhances the surface properties, especially for surfaces in tribological contact. In this study, the wear behavior of peened WC-W_2C FeCrCMnSi arc sprayed coatings is characterized and compared to conventional coatings under as-sprayed conditions. The resulting strain hardening effects were measured by mechanical response using nanoindentation. In addition, residual stresses at the surfaces were determined using X-ray diffraction and the $\sin^2\psi$ method.

Keywords: Machine Hammer Peening; Coating; Residual stress

1. Introduction

The production costs in high-strength sheet metal forming can be significantly reduced by increasing the lifetime of the dies and molds used [1]. A suitable solution to improve the abrasive wear resistance of tribologically stressed surfaces is the deposition of thermally sprayed tungsten carbide coatings on conventional steel workpieces. Due to the high deposition rate and the relatively low process costs, arc spraying is a widely used process for the application of such WC-W_2C coatings [2]. Hence, the high roughness of the coated surfaces has to be reduced prior to their tribological contact. In order to achieve the required surface quality, the protruding peaks of the topographies have to be removed by means of abrasive and electro discharge machining (EDM) processes or smoothed by incremental forming processes [1]. However, grinding and EDM are time-consuming processes and require adapted machining centers. Despite the high hardness of the tungsten carbides, roller burnishing enables the compression of the rough surface topography without damaging the coatings [3]. In addition, incremental cold forming processes such as roller burnishing and machine hammer peening (MHP) increase the microhardness and generate residual compressive stresses within the subsurface of the treated surface [4, 5].

This paper presents the first results of the mechanical post-treatment of arc sprayed tungsten carbide coatings by MHP. In order to characterize the machined surfaces, the microhardness, the residual stresses as well as the wear behavior were analyzed before and after the peening process.

2. Experimental setup and methods

2.1. Arc sprayed coatings

Disk-shaped C45 steel specimens (diameter = 40 mm) were used as substrate material. In preparation for the thermal spray experiments, the surfaces were grit-blasted with corundum (EKF 14) and cleaned in an ultrasonic ethanol bath. With regard to the feedstock material, a FeCrCMnSi cored wire, also referred to as Durmat AS-850 (*Durum Verschleißschutz, Germany*), with 50 wt.% cast tungsten carbides (eutectic WC/W_2C) as a filling material was used.

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The coatings were deposited on the substrates by the Smart Arc 350 PPG arc spraying system (*Oerlikon Metco, Switzerland*) using compressed air as an atomization gas. The process parameter settings were kept on a constant level for all samples (atomization gas pressure = 0.6 MPa, secondary gas pressure = 0.4 MPa, voltage = 30 V, current = 220 A, spray distance = 110 mm, gun velocity = 200 mm/s).

2.2. Annealing process

Arc spraying processes have a great potential to mainly prepare amorphously structured coatings because of the rapid cooling (about ~10^5°C/s) [6], which prevents long-range diffusion and avoids crystallization [7]. The application of Fe-based amorphous coatings, deposited by an arc spraying process, has been recently investigated [8]. The determination of the crystallographic lattice parameters by means of the X-ray diffraction (XRD) method, as it represents a non-destructive technique for measuring residual stresses in thermally sprayed coatings, is applicable for materials, which have a well-defined crystal structure [9].

Adequate measurability is attained by annealing at temperatures above recrystallization temperature, approx. 500 - 700°C for low alloyed steel. In this study, the heat treatment for all samples was conducted at 700°C within an exposure time of 6 hours.

2.3. Machine hammer peening process

In order to smooth the surface of the coatings, a subsequent machining was conducted on the five-axis machining center DMU50 eVolution (*Deckel Maho, Germany*) using the pneumatic MHP tool Forge Fix Air (*3S-Engineering, Germany*) with a spherically shaped carbide metal tip (tool diameter d_k = 12 mm) (**Fig. 1**). The adjusted tool diameter and the operating air pressure mainly influence the resulting degree of deformation of the surface topography. By these parameters, the contact area between tool and workpiece as well as the energy of the tool impact can be adjusted. The operating air pressure of the tool was p = 6 bar, resulting in an oscillating frequency of $f \approx$ 220 Hz. The feed velocity was v_f = 1000 mm min^{-1} and the line pitch a = 0.2 mm. Due to the superposition of the oscillation frequency and the feed velocity, the distance between two impacts of the tool was 0.075 mm.

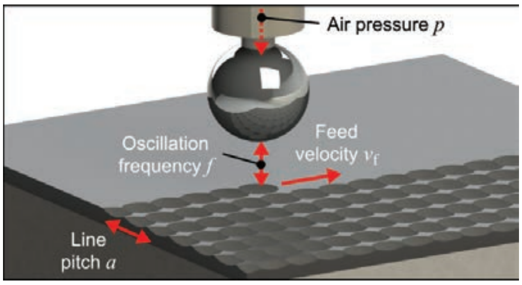

Fig. 1. Process kinematics of machine hammer peening

2.4. Analytic methods for coating characterization

Tactile and optical measurements were used for the characterization of the machined surface topographies. The roughness values according to DIN EN ISO 4287 were determined by means of a stationary roughness measurement system (*Mahr, Germany*). Furthermore, a confocal white light microscope (*Nanofocus, Germany*) was used to evaluate the surface topographies.

In order to examine the tribological behavior of the coatings, ball-on-disc tests (BOD) (*CSM, Switzerland*) were carried out, using alumina as a counter body. A load of 10 N was applied without a lubricant supply. As a result, the wear coefficient was calculated, based on the average volume loss at four positions for each wear track (three out of four samples) on a constant radius. The reduced, worn material was determined by the use of 3D-profilometry (*Alicona, Austria*).

Regarding the cross-section analyses, the coated samples were prepared by using diamond grinding discs and polishing cloths with a diamond suspension. Images of the microstructure of the coatings as well as across the wear tracks were taken, using a field emission scanning electron microscope (FE-SEM) type JSM-7001F (*Jeol, Germany*). EDS analyses, using the commercial software INCA (*Oxford Instruments, United Kingdom*), were utilized to examine the distribution of elements. Nanoindentation tests (*Agilent Technologies, USA*) were carried out on the surface in order to analyze the hardness and Young’s modulus.

The phase composition and the residual stresses on the coated surfaces after thermal spraying and annealing of the deposits were investigated by X-ray diffraction (XRD) (*Bruker, USA*) using the d-$\sin^2\psi$ method, which is a well-known non-destructive method to evaluate the residual stress [10, 11]. The coating was mainly composed of intermetallic phases of the Fe-W binary system, ternary phases like eta carbides (e.g. Fe_3W_3C), Fe and Fe-rich oxides. Here, the diffraction reflex at a large 2θ = 145.5° (with Fe-Kα), a superposition of the reflections of the phases Fe_xW_yC and Fe, was chosen due to the high Bragg angle, leading to very accurate measurements. This reflection represents the main phases Fe_xW_yC and Fe of the coating and allows obtaining a representative macroscopic stress value. The d-ψ data were evaluated using the Bruker software Leptos for residual stress evaluations. For the stress evaluation, the X-ray elastic constants (XEC) s_1 and $\frac{1}{2}s_2$ were needed. As the XECs of the phases in this coating were unknown, the Young´s modulus of the identical coating was determined by means of surface nanoindentation. **Fig. 2** shows some indents carried out at different spots around the heterogonous microstructure.

A mean value of 472 GPa (hardness H = 16.7 GPa) was determined for Fe_3W_3C which is in a good accordance with the values for Fe_3W_3C as reported in literature [12]. A macroscopic Young´s Modulus of 367 GPa and a Poisson ratio ν of 0.3 was assumed of the coating to calculate XECs based on the Voigt model [10, 11], which results in the following values: $s_1 = -0.817\cdot10^{-6}$ and $\frac{1}{2}s_2 = 3.542\cdot10^{-6}$.