Wear 346-347 (2016) 29–45

Contents lists available at ScienceDirect

Wear

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

Abrasive and erosive wear behaviour of nanometric WC–12Co microwave clads

Sunny Zafar, Apurbba Kumar Sharma*

Mechanical and Industrial Engineering Department, Indian Institute of Technology Roorkee, Roorkee 247667, India

ARTICLE INFO

Article history:
Received 4 September 2015
Received in revised form
2 November 2015
Accepted 4 November 2015
Available online 10 November 2015

Keywords:
Microwave cladding
Cermets
Surface analysis
Three-body abrasion
Solid particle erosion

ABSTRACT

The present work examines the abrasive and the erosive wear performance of WC–12Co microwave clads. Cladding of micrometric and nanometric WC–12Co powders was carried out on austenitic stainless steel substrate using microwave hybrid heating technique. The micrometric clads exhibited the presence of skeleton structured carbides uniformly distributed in the metallic matrix. On the other hand, presence of clusters of nanocarbides was observed in the nanometric WC–12Co clads. The average microhardness of the nanometric (1564 ± 53 HV) was approximately 1.37 times higher than the micrometric clad (1138 ± 90 HV). A dry sand rubber wheel apparatus using silica sand as the abradant was used to evaluate the three body abrasive wear performance of the clads at various loads (30, 60 and 90 N). The erosive wear performance of the clads was evaluated at various impact angles (30°, 60° and 90°) using solid particle erosion using alumina as the erodent. Lower binder mean free path, higher microhardness and enhanced carbide volume fraction lead to the higher abrasive and erosive wear resistance of the nanometric WC–12Co clads.

1. Introduction

A major challenge in technological development is to continue to meet requirements for new materials for use in progressively stringent conditions. Engineering components such as in petrochemical, power and aerospace suffer surface degradation primarily due to wear. Abrasion and erosion are ubiquitous forms of surface degradation of engineering components. In abrasive wear, loss of material takes place by hard particles or protuberances on the counter surface. There is a possibility of three-body abrasion as well, when abrasive particles are free to roll and slide between the two dissimilar surfaces [1,2]. Erosive wear is caused by hard particles entrained in a fluid or a gas stream striking the surface [3]. Therefore, use of wear resistant materials in the form of coating/cladding is a pragmatic solution to combat wear [4–7].

Recently, composite coatings consisting of hard phase embedded in the tough metal binder are being increasingly used to minimise wear. The WC–Co based materials are preferred due to their superior abrasive and erosive wear resistance [8–11]. The WC phase provides the hardness while the Co phase provides the toughness to the overlay material. It has been reported that the abrasive and erosive wear resistance of the WC–Co based materials depends on several factors like distribution of the carbide particle size, hardness of the carbide phase and volume fraction of the carbides. Therefore, nanostructured materials in the form of coatings have been popular to impart wear resistance of various industrial components [2,12–19]. Nanostructured materials provide the advantage of having a higher carbide area for a given wear surface. This is due to the higher surface to volume ratio of the nanostructured materials.

Thermal spraying and its variants have been traditionally a popular choice to deposit nanostructured WC–Co based coatings [12–21]. However, the thermal sprayed coatings are not metallurgically bonded and are also chemically inhomogeneous [22]. Thermal spray deposits often present issues like low strength, exfoliation, cracking and spalling while exposed to wear conditions. Several studies were conducted on post processing of thermal sprayed coatings to improve their density, increase homogeneity and reduce porosity [22–24]. Another major concern with the thermal spray process is high ratio of surface area to volume of the nanostructured WC–Co powder that leads to the decomposition of the carbide phase during the thermal spray process [25,26].

Laser cladding, on the other hand, offers to mitigate the limitations of thermal spraying attributed to its characteristics like strong metallurgical bonding to the substrate and excellent control on dilution [27]. The clad is formed due to combinations of absorption of laser radiation (electromagnetic energy) by the clad powder particles and consequent heat conduction and melting of the particles with a thin layer of the substrate followed by rapid solidification [5]. Rapid solidification

* Corresponding author. Tel.: +91 1332 285421; fax: +91 1332 285665.
E-mail addresses: sunny.zafar9@gmail.com, sunzfdme@iitr.ac.in (S. Zafar), akshafme@gmail.com, akshafme@iitr.ac.in (A.K. Sharma).

http://dx.doi.org/10.1016/j.wear.2015.11.003
0043-1648/

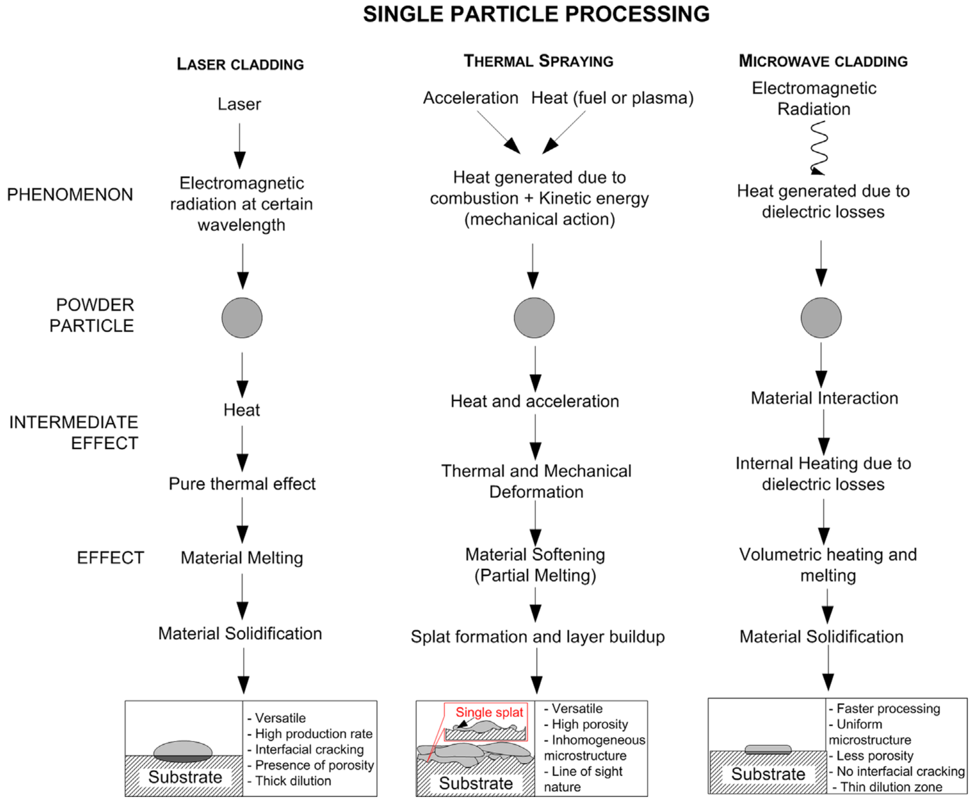

Fig. 1. Schematic diagram illustrating single particle processing.

results in finer microstructures, which increases the hardness and improves wear resistance [28].

Recently, application of microwave cladding for developing wear resistant surfaces has been successfully explored [29–34]. Attributes like faster processing, uniform microstructure and lower thermal gradient make microwave cladding one of the pragmatic surfacing solutions. It was earlier reported that WC–Co based clads, developed through microwave cladding, exhibited only traces of W and W_2C phases [6,31–34]. Hence, it is reasonable to understand that microwave energy can minimise the decomposition of the carbide phase. Higher surface area of the nanostructured materials also results in better microwave absorption leading to faster and volumetric heating of the clad powder.

The wear behaviour of the engineered surfaces through these three important techniques can be better understood by correlating with their mechanism of formation. The principles of formation of the three surfaces are schematically illustrated through “single particle processing” concept in Fig. 1. In laser cladding, the electromagnetic radiation is absorbed by the clad powder particles according to their absorptivity. Depending on the interaction time, the electromagnetic energy causes local melting of the clad powder, which forms the engineered layer upon solidification (Fig. 1). Complete melting and solidification yields dense microstructure. However, in laser clads, there are a few concerns regarding development of residual stresses due to high thermal gradient, solidification cracking and the presence of porosity [28]. Therefore, the presence of porosity and microcracks leads to spalling of the laser clad layer under severe wear conditions. In case of thermal spraying, the wear resistant layer gets built up due to combined action of rapid acceleration and intense heating. Molten/semi-molten particles, on impact with the substrate, get transformed into splats or lamellae (Fig. 1(inset)). The subsequent splats get deposited onto the previous splats in a layer by layer structure (Fig. 1). These individual splats get significantly deformed with respect to their original particle geometry; however, in most of the cases still retains the trace of a separate particle boundary as can be visualised in Fig. 1. Thus, the splats are mechanically anchored on the substrate and are not metallurgically bonded. This results in an inhomogeneous microstructure with the presence of pores and cracks [22]. Such microstructure thus, fails to exhibit superior wear performance, although wear resistance increases to certain extent owing to enhanced surface hardness. The splats also exhibit a tendency to decohere while subjected to wear conditions. In microwave processing, the heat is generated inside the powder particle due to dielectric losses which causes volumetric heating and subsequent melting. The molten particle causes the substrate temperature to rise to its melting point and get fused (Fig. 1). On solidification, a metallurgically bonded clad is obtained with dense and uniform microstructure, negligible porosity and the absence of solidification cracking [6,31–34]. Consequently, the microwave clads exhibit improved wear resistance. Some wear data of typical laser clad, thermal spray deposit and microwave clad of WC–12Co material are presented in Table 1. The wear data indicate relatively high wear resistance of microwave clads as compared to the laser clad and thermal spray deposits.

The potentially promising microwave cladding has not been explored well, in particular, while developing nanostructured clads. Detailed data on the wear behaviour of nanometric clads might provide a new solutions to combat wear and would open up a new research domain. Therefore, the present work investigates the wear behaviour of WC–Co cermet clad developed by microwave cladding. The WC–12Co clads were deposited on SS304 stainless steel using micrometric and nanometric WC–12Co powders using MHH technique. The microstructures and the microhardness of the microwave clads were evaluated to understand the wear behaviour of the WC–12Co clads. The load is an important parameter during wear, hence three body abrasive wear tests were carried out under different loads using dry sand rubber wheel (DSRW) apparatus. The erosive wear performance of the micrometric (MM) and nanometric (NM) clads was evaluated at different impact angles in an air-jet erosion (AJE) test rig at room temperature. The wear results were correlated with the top and cross-sectional SEM micrographs of the worn surfaces. The