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Application of hardmetals as thermal spray coatings

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ABSTRACT

Thermally sprayed hardmetal coatings have a typical thickness within the range 100–500 μm. Thus, thermal spray enables the functionality of hardmetals to be realized on the surface of large parts, which cannot be produced by powder metallurgy for technical and economical reasons. This article reviews the different types of thermal spray processes, with particular focus on the high velocity HVOF and HVAF deposition techniques which are of most relevance to the application of hardmetal coatings. Feedstock powder preparation technologies are presented. The majority of hardmetal thermal spray coatings are based either on WC or Cr_3C_2 or hard phases appearing as a result of their interaction. As an alternative, TiC-based compositions are most intensively studied. Thermal spraying generates significant changes in the hardmetal chemical and phase compositions between the feedstock powder to the sprayed coating. Coating formation and microstructures as well as selected properties, such as hardness, the effect of heat treatments and the oxidation in service, as well as corrosion resistance are discussed. As an example for wear protection applications, abrasion wear resistance is shortly discussed.
This paper is a partly updated and condensed version of the chapter: "Coatings by thermal spray" in the book "Comprehensive Hard Materials", V.K. Sarin (Editor-in-Chief) & D. Mari & L. Llanes (Vol. Ed.), Vol. 1 (pp. 471–506), Elsevier, 2014.

1. Introduction

Thermal spray processes represent an important and rapidly growing group of surface modification technologies. They use a very wide range of solid feedstock materials (including metals and alloys, hardmetals, ceramics and polymers), mostly in the form of particles, wires, and suspensions. Hardmetals are one of the most important groups of materials processed by thermal spray processes into coatings. For coating formation, plastic deformation of the feedstock particles at the moment of impact is a precondition after acceleration inside or outside of the spray gun. In most of the thermal spray processes this is achieved by full or partial melting of the feedstock material. The substrate remains unmelted during spraying, with the splats adhering to the substrate primarily through mechanical bonding. Thermal spray enables the functionality of hardmetals to be realized on the surface of large parts, which cannot be produced by powder metallurgy for technical and economical reasons [1].

The different thermal spray processes can be characterized in terms of particle velocity and process temperature, as shown in Fig. 1. Economic parameters such as deposition efficiency (DE) and powder feed rates are additional factors for the realization of efficient coating solutions. With respect to hardmetal coatings, coating development is currently driven by the search for the optimum combination of particle velocity and process temperature to generate dense coatings at high DE and high powder feed rates.

A general overview of thermal spray technologies can be found in several books [4–6], or a chapter of a handbook [7]. A more specialized book deals with coating preparation by high velocity oxy-fuel (HVOF) spraying alone [8].

High velocity oxygen fuel (HVOF) spraying is the current state-of-the-art process of hardmetal coating preparation by thermal spraying. This process is illustrated in Fig. 2. Coatings are usually prepared from feedstock powders consisting of small hardmetal particles, typically in the size range 10–45 μm. Thus, preparation of thermal spray coatings can also be considered as a two-stage shaping technology for hardmetals: first stage consisting of the feedstock powder preparation, second stage consisting of the spray process. WC–12Co, WC–17Co, WC–10Co–4Cr, WC–20'CrC'–7Ni and Cr_3C_2–(20–25)NiCr (all compositions in weight percent unless otherwise indicated) are the main commercially available compositions. In the past, progress in coating performance was mainly achieved through improvements in the spray processes, while the main commercial feedstock compositions remained unchanged. The coatings are typically sprayed to a thickness within the range of 100–500 μm. The coating properties are dependent upon the combination of the thermal spray process conditions and the composition and properties of the feedstock material. During spraying a number of metallurgical processes such as carbide dissolution in the

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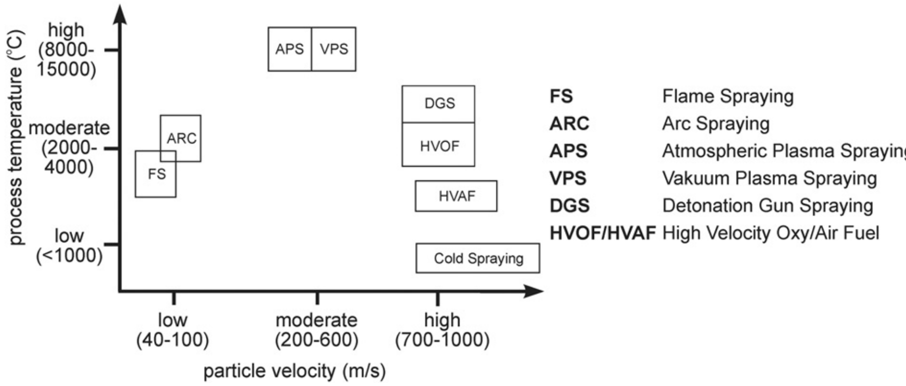

Fig. 1. Schematic presentation of the combination of process temperature and velocity for the different spray processes (FS—flame spraying, ARC—arc spraying, APS/VPS—atmospheric/vacuum plasma spraying, DGS—detonation gun spraying, HVOF—high velocity oxy-fuel spraying, HVAF—high velocity air–fuel spraying) [2], modification of an older version [3].

binder, and changes in the chemical and phase compositions of the material occur in extremely short periods of time. As for bulk hardmetal production, control of the carbon content is a critical issue. The process of coating formation is characterized by high cooling rates leading to the existence of high temperature and non-equilibrium phases and nanocrystalline structures, particularly in the binder phase. The spray process also generates high stresses within the coating material.

The 'elementary act' of coating formation is illustrated in Fig. 3a showing a deformed hardmetal powder particle ('splat') after impact on the substrate surface [1]. The coating is formed from a concentrated particle stream to give a pass, a number of parallel passes are necessary to cover a surface. To obtain the required thickness of the coatings this procedure is normally repeated several times. The top view of an as-sprayed hardmetal coating is shown in Fig. 3b.

Although both powder metallurgy and thermal spray use basically the same hard phase-binder metal composite materials, the technical development of both areas occurred practically independently from each other. Furthermore, the traditional terminology for these composites is different in each area and often leads to misunderstandings [1]. Bulk parts prepared by powder metallurgy, are termed 'hardmetals' or 'cemented carbides', where the term 'cemented carbides' is used more strictly for WC-based composites only. For the term 'cermet' different definitions were given [10]. Most often it is related to TiC-based composites which are characterized by the appearance of core–rim structured cubic hard materials in a metallic binder (mostly nickel). In thermal spraying all hard phase based coatings are usually designated as 'carbide coatings', but sometimes also as 'cermets'. It appears that the designation 'hardmetal coatings' best describes the state-of-the-art thermal spray coatings of this class of material.

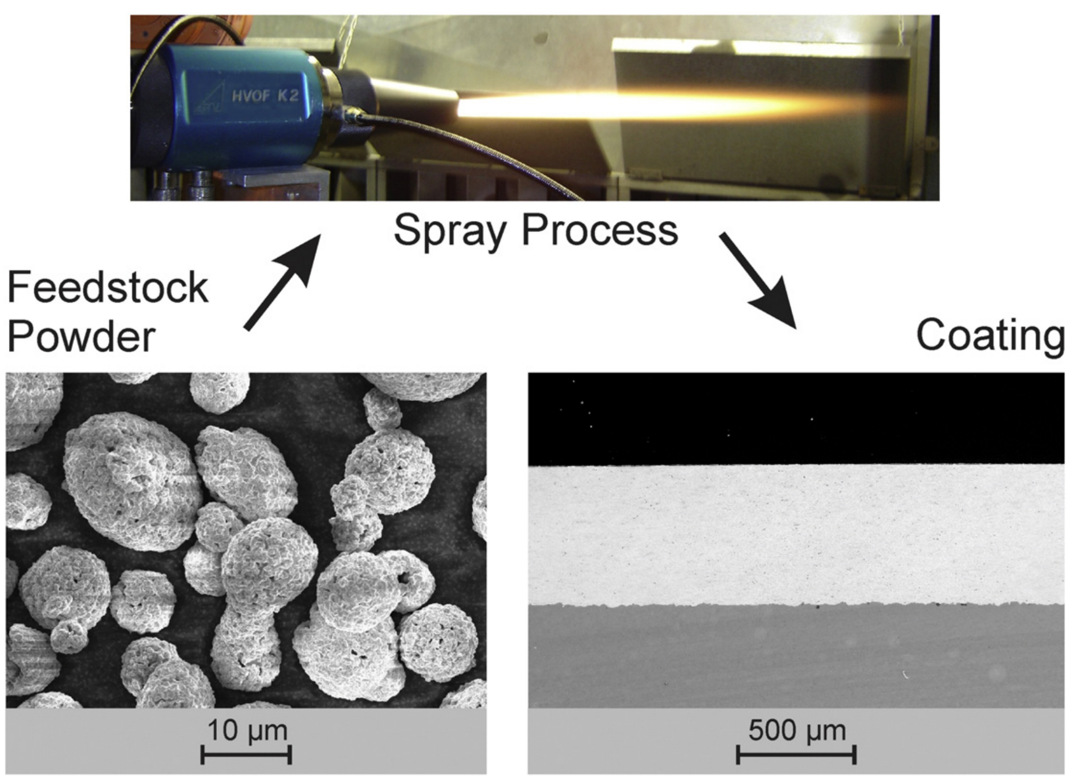

Fig. 2. Preparation of a hardmetal coating by the high-velocity oxy-fuel (HVOF) spray process: SEM micrograph of the agglomerated and sintered feedstock powder, (left); the HVOF spray process (above); SEM micrograph of a metallographically prepared cross section a dense WC–17Co coating on a metallic substrate (the black area at the top is the cured resin) (right); modification of an older version [9].