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Zhongyu Piao · Cong Ding · Wentao Hou · Zhenyu Zhou

Performance of Plasma Sprayed Coating

Rolling Contact Fatigue Behavior and Life Evaluation

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Contents

Chapter 1
Rolling Contact Fatigue and Thermal Spraying Technique

Abstract With the booming development of the remanufacturing industry, the quality control and evaluation of remanufactured products have attracted much attention. The basic theories, such as the evolution law of service life of the surface of remanufactured products processed by surface engineering technology, have become a hot issue in the field of remanufacturing research. This chapter mainly introduces the development history of thermal spraying technology, the wear resistance service life of thermal spraying coatings, the application of online monitoring technology in friction and wear, and the research status of thermal spraying quality control technology.

Keywords Remanufacturing industry · Thermal spraying technology · Thermal spraying coating · Online monitoring technology

1.1 Development of Thermal Spraying

Thermal spraying technology is a typical surface engineering technology and has been widely used in remanufacturing engineering. According to Chinese Standard GB/T18719-2002, thermal spraying technology is a method of heating spraying materials to a melten or semi-melten state via a heat source, and spraying them at a certain speed to deposit on the pretreated substrate surface to form a coating [1]. The essential process of thermal spraying is shown in Fig. 1.1.

Thermal spraying technology has been developed for nearly a hundred years, and it has developed most rapidly in the past 30 years. Scholars from various countries are committed to the development of a new spraying technology and new spraying materials. In essence, all of the thermal spraying technologies can be basically classified into two categories. The first type is called as combustion method, which obtains sufficient energy through the combustion of hydrocarbon fuels to melt the spraying materials. This method can be considered to be developed from the metal coating technology in early twentieth century. Specifically, the spraying material is melted by using the oxyacetylene flame and then deposited on the metal surface, so the coating

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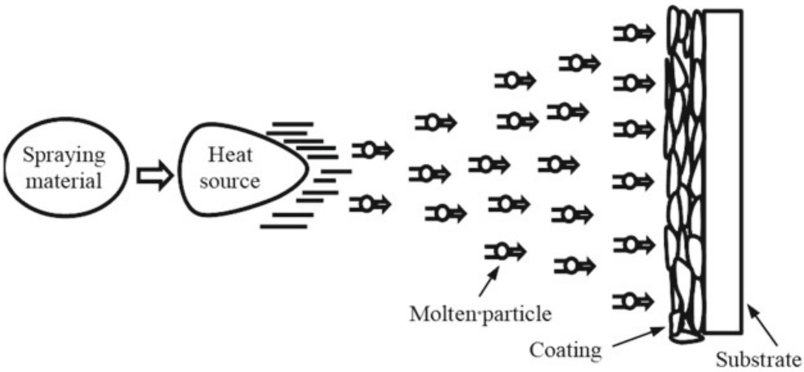

Fig. 1.1 Schematic of formation mechanism of thermal spraying technique

is formed [2]. In 1910, M.U. Schoop, a PhD of engineering in Switzerland, invented the world's first metal spraying device "metal solution spraying". Since then, Schoop has worked on the improvement of the spraying device, so that the spraying material can be simultaneously heated, atomized and broken down. And he successfully developed the wire flame spray gun in 1912, making the thermal spraying process practical for the first time [3]. Subsequently, the technology was introduced into Japan, and it achieved a rapid development, until now it is still often used in multiple fields, such as flame spraying. The second type is called as heat source method, which uses arc and plasma as a heat source to provide enough energy for metal melting, so as to form a coating. Schoop started the design of arc spraying gun in 1913 and successfully developed a practical arc spraying gun in 1916. On the basis of his research, Japanese, German and American scholars have further studied and improved this technology so far. In 1920, Japanese scholars invented a spraying device with the heat source of AC arc. But their spraying device was not promoted due to the disadvantages of an unstable AC arc, low efficiency and poor coating quality. Afterwards, German scholars used a DC power supply instead of AC power supply, and the arc spraying technology has been popularized and applied in practice. In the middle of the last century, American scholars successively developed the explosive spraying and plasma spraying technologies, which met the urgent needs of aviation, atomic energy, missiles, rockets and other highly advanced technologies for high melting point and high strength coatings. The ceramic coating was successfully prepared in 1965 to improve the thermal insulation performance of aero-engine. In the 1980s, Browing Company of United States successfully developed the supersonic flame spraying technology and device, making the thermal spraying technology almost free from the limitation of spraying materials. Via increasing the velocity of particles in the spraying process, the bonding strength between the coating and substrate and the coating quality are improved, which greatly broadens the application range of thermal spraying technology. The development process of thermal spraying is shown in Fig. 1.2 [4].

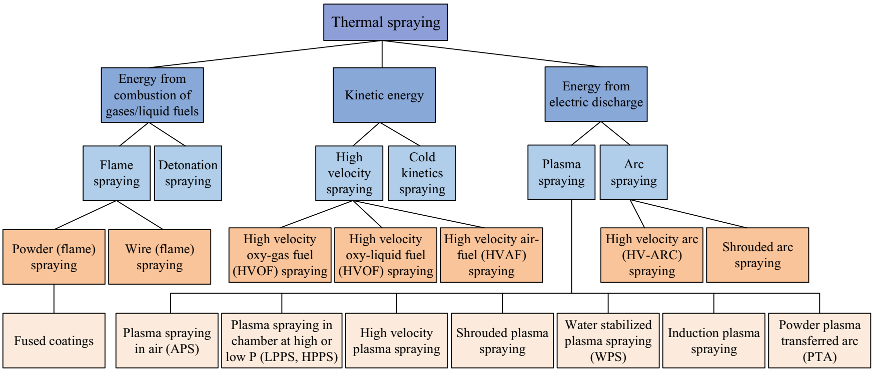

Fig. 1.2 Development of thermal spraying processes

It can be seen that different types of spraying methods are continuously emerging with the progress of thermal spraying technology, which greatly expands the application field and scope of thermal spraying technology. Designers can choose an appropriate spraying method according to the needs of actual working conditions. Figure 1.3 shows the distribution of heat source temperature and flame flow velocity of thermal spraying techniques [1], in which the plasma spraying has obvious advantages in heat source temperature, but also has a very fast flame flow velocity. Plasma spraying is a widely used and mature spraying technology. Its significant feature is that plasma flame flow with high temperature can heat various spraying materials to a molten state. The main process of plasma spraying is the generation process of plasma flame, the melting of particles in plasma flame and the forming process of coating [5]. In plasma spraying, gas is generally used as a heat source or propellant of spraying material, and the current density and the temperature of arc are controlled by the adjustment of the nozzle diameter. The interaction between gas and arc leads to the decomposition and ionization of gas, and the formation of plasma flame stream [6]. With an increase of gas flow via plasma flame stream, multi-atomic gas releases a lot of energy through ionization and decomposition, and single-atomic gas can obtain high energy and temperature through ionization. Due to the combined energetic effects of gas ionisation and decomposition, the plasma flame flow from the nozzle has high temperature and velocity, which is enough to completely melt the spray particles [7]. Pure nitrogen and argon are commonly used as the main gases of plasma spraying, while hydrogen and helium are often used as the secondary gases of plasma spraying. The secondary gas can improve the ionization voltage of the main gas and the thermal conductivity of the plasma flame flow, so that the plasma spraying can still obtain higher temperature at lower power. In the 1980s, plasma spraying technology was first introduced into the aerospace and other military fields, and the technology has made great progress. So far, it still occupies the largest share in the thermal spraying market and has a great application prospect and development space. Table 1.1 lists the application proportion of the main thermal spraying methods [8].

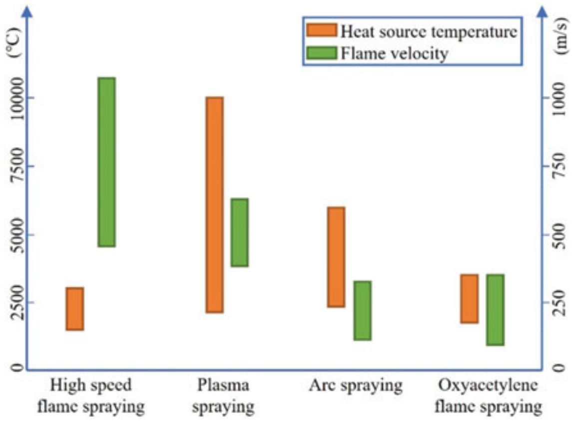

Fig. 1.3 Distribution of temperature and velocity of thermal spraying techniques

Table 1.1 Applied proportions of the main thermal spraying techniques

Thermal spraying method	1960s	1980s	2000s
Wire flame spraying	≥70	11	4
Flame powder spraying	≥70	28	8
Wire arc spraying	15	6	15
Plasma spraying	15	55	48
High velocity flame spraying	–	–	25

The Key Laboratory of National Defense Science and Technology of Equipment Remanufacturing Technology in China independently developed a set of high-efficiency plasma spraying device. Under the premise of low energy consumption and small gas flow, the supersonic plasma spraying was realized, which significantly improved the coating performance. The equipment as a whole reached the international advanced level. The core technology of supersonic plasma spraying gun is international leading, authorized the national invention patent (No. 01101077.0), and won the first prize of military science and technology progress in 2002, and won the second prize of national science and technology progress in 2003. This high performance spraying device mainly includes supersonic plasma spraying gun, powder feeder, water cooling device, computer control cabinet and power. The schematic diagrams of the supersonic plasma spray gun and the ordinary plasma spray gun are shown in Fig. 1.4. It can be found that the length and density of plasma flame formed by high-efficiency plasma gun are much higher than those of ordinary plasma gun. Moreover, experimental studies have shown that compared with ordinary plasma spraying device, this high-performance plasma spraying device can prepare high-quality ceramic and metal coatings at low cost [9]. The coating samples used in this study are prepared by this equipment.

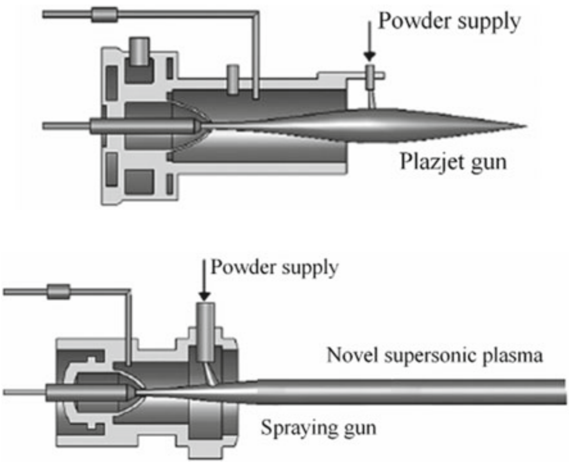

Fig. 1.4 Comparison between SPSG and Plazjet gun, with permission from [10]

1.2 Research Status of Wear Resist Thermal Spraying Coating

For the thermal spraying technology, the coating materials with different properties and different spraying process methods, can be used to prepare function coatings with the performances of wear reduction and resistance, corrosion resistance, high temperature resistance, thermal barrier function, catalytic function, electromagnetic shielding and absorption, conductive insulation, and far-infrared radiation. These coatings are widely used in various fields of national production and have achieved relatively good practical effects. In particular, the wear resistance of thermal spraying coatings is of utmost concern. Surface wear failure is one of the most common failure modes for the mechanical parts and engineering components, which causes huge economic losses and seriously restricts the service performance of civil equipment and the combat performance of military equipment. Foreign data show that friction consumes 1/3 of the world's disposable energy, and more than 50% of the vicious accidents of mechanical equipment are caused by lubrication failure and excessive wear. The loss caused by wear and friction in developed countries such as United States, Britain and Germany, accounts for approximately 2–7% of annual GDP. With the rapid development of Chinese national economy, great changes have taken place in economic structure, total equipment and management mode, and the loss caused by friction and wear in various industries has also increased accordingly. According to the reports of the advisory research project of the Engineering Institute, the loss caused by friction and wear in China in 2006 was about CNY 950 billion [11], accounting for 4.5% of Chinese GDP in that year. The huge loss caused by friction and wear to the national economy is obvious.