別紙４（課程博士）

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Abstract

論文内容の要旨　（博士）

Title of Thesis 博士学位論文名	Study on operational characteristics of low power atmospheric pressure microwave plasma spray method (低電力大気圧マイクロ波プラズマ溶射法の動作特性の研究)

(Approx. 800 words)

(要旨　1,200 字程度)

Plasma spraying method is the most versatile coating technique for the deposition of high melting point materials such as ceramics and cermet which is used in the application of wear, corrosion and heat resistance. It uses the heat source generated by direct current, radio frequency or microwave as the power source to melt the spray particles which were injected either axially or radially inside the plasma plume. The accelerated particles will collide and impinged onto the surface of the substrate to fabricate the coating. Conventional plasma spray method possesses very high temperature plasma (above 10000 K) at high power (above 40 kW) which is very useful to fabricate high melting point material coating. However, the excessive heat input from the plasma may influence in deterioration of material phase structure in some material such as ceramics and degraded some functions as well as the difficulty to fabricate coating onto low melting point substrate such as plastics, resin and polymers. Here, the need of using low power plasma to reduce the heat input onto spray and substrate material is being focused and microwave plasma is seen as a good candidate due to its stability in wide range of pressure and easy to be generated at low power. Microwave is rarely been used as the plasma power source due to the unknown mechanism and the stabilization factor of the process. Our research group has managed to generate the plasma with microwave at 1.0 kW of power in atmospheric condition and succeeded to fabricate Cu, Al and hydroxyapatite coating. However, the mechanism and characteristics of the process is not studied well yet. Thus, the main objective of this research is to study the operational characteristics of low power microwave plasma spray method and its applicability in reducing heat input towards spray and substrate materials as the specialty of this technique. Moreover, the improvements and renovation of the spray device are also studied and presented.

Firstly, the study on operational characteristics of microwave plasma spray in compare to conventional plasma spray is conducted. Here, it is known that the microwave plasma spray method possesses the heat efficiency comparable to the conventional plasma spray which is at the average of 30 %. The microwave plasma can be generated and stabilized down to 0.3 kW as the result received on plasma ignition study. The study on plasma and spray particles behaviour of microwave plasma spray shows that the plasma has the average temperature of over 4000 K and particle velocity of 135 m/s at the maximum parameter. The substrate temperature study shows that the suppression of temperature is able to be achieved for the application onto heat susceptible substrates.

The next study is worked on the applicability of microwave plasma spray in reducing the heat input onto substrate material. Here, the Cr coating onto carbon fiber reinforced polymer (CFRP) was conducted. The CFRP is focused in recent studies due to its property of high strength to weight ratio but due to the polymer matrix, the material surface struggles at wear and corrosion resistance in which the hard chrome coating is crucial to overcome this disadvantage. The conventional method for this coating production is hard chrome plating. However, this method needs control environment due to hazardous waste and slow in production which made the microwave plasma spraying method to be seen as the alternative method. Chromium coating has been successfully deposited onto CFRP substrate with coating microhardness higher than the average in hard chrome plating at above 1100 Hv. The emergence of Cr oxides confirmed by X-ray diffraction analysis is thought to be the factor contributing towards the increasing hardness of the coating. Chrome particles were mostly gathered onto the carbon fiber which appeared after the resin parts were melted by the plasma heat and this suggest that the mechanism of bonding is mostly by the mechanical interlocking.

The research is furthered on the applicability of microwave plasma spraying method at suppressing heat input onto spray materials where the study on coating deposition of TiO_2 with low heat effect onto spray material is conducted. Titanium dioxide is a photocatalyst material focused in recent studies because of its magnificent properties where it possesses photocatalytic activity such as the ability to remove the air pollution substance and deodorizing function. Generally, the deposition method of a titanium dioxide coating is carried out by the fixation of titanium dioxide powder with an organic system binder but it will let the degradation of the powerful catalytic reaction of a titanium dioxide. Therefore, thermal spray is thought to be the alternative method but this method will induce transformation from anatase phase with high photocatalyst activity to rutile phase with low photocatalyst activity due to excessive heat. As a result, the maximum of 83 % of anatase content rate is achieved at optimum condition which suggests that the suppression of heat input onto spray materials is successfully obtained by using microwave plasma spray method. From the coating deposited by 99 % of rutile content rate titanium dioxide powder, the anatase content rate increased inside the as-sprayed coating proved that the nucleation of anatase phase occurred during the spray. The anatase content rate inside the as-sprayed coating is increased with the decrease of substrate temperature due to rapid cooling.

In fifth chapter, the research tasks and future perspectives of low power microwave plasma spray device are discussed. Here, the research tasks are divided into three categories which cover the improvement in coating deposition, the device itself and enhancement that should be made. Some of the required optimizations of the current device are particle velocity, powder feeding method, antenna structure, etc. For improvement of particle velocity, electromagnetic pinch thrust by magnetic nozzle is considered and the experimentations as well as the magnetic field simulations are conducted. Simulation results help in obtaining the structure of magnetic nozzle and experimentation results show some improvement in particle velocity and plasma temperature by the use of magnetic nozzle. However, due to the elevated particle velocity is still low, further investigation should be made.

In conclusion, this newly investigated method proved its specialty in low power plasma spray at extremely low power and its efficiency to deposit coating with suppress heat input effect onto substrate and spray materials. Future research should be conducted to improve some of its feature towards realizing this method in the mainstream of thermal spray technique.