学 位 論 文 内 容 の 要 旨

DISSERTATION ABSTRACT

博士の専攻分野の名称　博士（工学）　氏名　德永 透子

学 位 論 文 題 名

Title of dissertation submitted for the degree

Development and Characterization of Al-coated Mg Alloy

(Mg/Al クラッド材の開発および特性調査に関する研究)

Mg alloys are the lightest metal materials among practical alloys for structural use. Mg alloys possess many other attractive properties such as good recyclability and high ability of vibration absorption and electromagnetic shielding. Owing to these superior properties, they have attracted a great deal of attention from a number of industries in a broad range of areas. Specifically, Mg alloys capture the attentions of automobile industry people, who are ambitious to achieve the weight reduction of vehicles in reaction to the legislation regarding to the global environmental problems.

However, the practical applications of Mg alloys have been limited because they have extremely poor corrosion resistance. The techniques for covering the drawback are still developing, attributed to the short history of Mg alloys gaining recognition for their potentials.

Coating is known as efficient techniques to prevent corrosion. In fact, a large number of coating techniques has been proposed e.g. conversion, anodizing and electroplating. However, these techniques require complex procedures and appropriate pretreatments due to the high reactivity of Mg alloys. Furthermore, in order to realize the sufficient corrosion protection, coating must be uniform, well adhered, pore free and strong enough for an applicable environment. As above, many severe demands are required to achieve the corrosion protection of Mg alloys, therefore, promising coating techniques have been still anticipated for the further development and applications of Mg alloys.

The present author addresses development of a new coating technique by means of a hot extrusion technique, which is simple, cost-effective and basically free from above-mentioned problems. In this technique, Al is selected as a coating material because of its excellent corrosion resistance and light weight. The main purpose of this study is development and characterization of the Al-coated Mg alloy fabricated with the aforementioned extrusion technique. This study demonstrates a possibility of wide and practical use of Mg alloys, which will be indicated by dramatically improved corrosion resistance with thick Al coating, the excellent bondability and deformability of the Al coating layer during superplastic deformation of the Al-coated Mg alloy sheet. Several issues are tackled in this study by the multi-disciplinary approach with both experimental and numerical methods and are explained in detail below.

The Al-coated Mg alloy bars and plates were successfully fabricated by the hot extrusion technique in the author's preliminary experimental study. Importantly, it was confirmed that the extruded bars and plates exhibit excellent corrosion resistance. However, in practice, sheet products of Mg alloys are often used rather than bars and plates. Therefore, the feasibility of sheet fabrication based on the present technique is important information, which demonstrates the practical applicability of the present technique. Thus, in this study, the sheet fabrication is attempted and its characteristics are investigated. Furthermore, the precise control of the thickness of Al coating is the important issue in development of the present extrusion technique. The coating thickness should be dependent on many process parameters such as extrusion temperature, ram speed and also the strength of core and coating materials. However, empirical elucidation of such dependencies requires a considerable amount of time and

energy. Thus, in order to clarify the dependencies of the coating thickness on the parameters, the sensitivity analysis is performed after numerical simulations of the extrusion process. Consequently, the dependencies and the optimal extrusion condition for the uniform thickness coating are elucidated and the control of coating thickness is achieved. As described above, the present study is mainly intended to the development and characterization of the Al-coated Mg alloy. This thesis consists of 8 chapters and the organization is described below.

In Chapter 1, the social demands and characteristics of Mg and its alloys are illustrated. The importance of corrosion resistance improvement of them is described. The early-developed coating techniques are introduced and the remained problems in those techniques are pointed out. Lastly, the purpose of this study and organization of this thesis are described.

In Chapter 2, the author's preliminary experimental study *viz.* the aforementioned coating technique by using a hot extrusion is explained and the chemical and mechanical properties of the produced Al-coated Mg alloy are illustrated.

In Chapter 3, the flow stress model of the focused Mg alloy is developed for the numerical simulation of the extrusion process, which is performed to achieve the precise control of the Al coating thickness. In the numerical simulation, flow stress models have a considerable influence on the accuracy of the simulation by describing the rheological properties of the materials. Therefore, the flow stress model is developed by a combination of the inverse analysis and optimization process.

In Chapter 4, the effects of extrusion parameters on the coating thickness uniformity are evaluated by the sensitivity analysis with the help of the numerical simulation. The effects of the following five parameters are evaluated; (1) initial thickness of the coating material plate, (2) extrusion temperature, (3) ram speed, (4) die angle and (5) the strength of core and coating materials. It has been found that the initial thickness of the coating material plate and die angle are the most significant parameters that determine the coating thickness uniformity. Accordingly, the optimal condition to achieve the uniform thickness coating has been indicated.

Chapter 5 focuses on the feasibility of fabrication of the Al-coated Mg alloy sheet with a view to the practical application of the present coating technique. It has been found that even after the severe forging deformation through the sheet formation, the Mg/Al bonding is maintained and therefore, the Al-coated Mg alloy sheet exhibits an excellent corrosion resistance.

In Chapter 6, the tensile properties of the Al-coated Mg alloy sheet is investigated, since the deformability and mechanical properties of the sheet are of primary importance to practical application of the sheet. The sheet showed a large tensile elongation of 550 % at a temperature of 573 K and at a strain rate of $1.0 \times 10^{-3}\ s^{-1}$. Notably, the Al coating continuously covered the Mg alloy substrate without breaking, despite such a large elongation.

Chapter 7 focuses on the deformation mechanism of the Al-coated Mg alloy sheet. Firstly, the strain rate sensitivity index of the sheet was investigated and found to be approximately 0.2 and 0.4 at 473 K and at 573 K, respectively. Therefore, it has been found that the large elongation of the sheet should be classified into the superplastic deformation. The individual tensile behaviors and deformation mechanisms of the Mg alloy and pure Al are described. The Al exhibits only 40 % of elongation when it is tensile-tested individually, while the Mg alloy exhibits as large as 800 % of elongation. However, the Al was elongated to 550 % as described above when it was used as the coating layer on the Mg alloy. Thus, the large elongation of Al as the coating on the Mg alloy should be attributable to the good bonding between the Al coating and the superplastic Mg alloy substrate. Furthermore, the large elongation of the Al-coated Mg alloy sheet is explained and discussed also in the light of microstructure.

Finally, the contributions and future perspectives of the present study are summarized in Chapter 8.