（様式乙 1-3-2）

THE SUMMARY OF Ph.D. DISSERTATION

School of Integrated Design Engineering	Doctor Identification Number	SAWAI, Takeshi

Title

Evaluation of Friction Welded Joints of Aluminum Alloys by Heat Input

Abstract

Generally, in order to obtain sound welded joints by the friction welding process, optimum welding conditions are selected with reference to a number of preliminary experimental results or conventional data. Thus, the preliminary experiments and past experiences are always important for the selection of friction welding conditions, because the estimation of the optimum welding conditions using theoretical analysis is difficult. Especially, the optimum welding conditions change, when the kind of material or welding machine changes. Furthermore, the estimation of suitable welding conditions of new materials, which have never been applied to the friction welding process, is also difficult. Accordingly, some methods to select the optimum welding conditions by analyzing many experimental results have been studied and proposed. However, general solution was not obtained by these analytical methods, because the practical welding factors, such as upsetting speed, brake timing, change of rotational speed during braking time and etc. varies with each braking type friction welding machine. Inertia type friction welding machines have also unstable factors, such as friction torque, that is friction coefficient at a friction surface, which changes transitionally during welding.

Therefore, as an evaluation value to estimate the validity of the friction welding condition, the heat input generated during welding was remarked in this study. The heat input is a value corresponding to the fundamental phenomena in friction welding, and is not influenced by the individuality of friction welding machines. Furthermore, the heat input has a merit to be easy to monitor.

In this study, the heat input was divided into two categories of friction heat input and deformation heat input. Furthermore, the friction welding process was divided into the friction stage and the upset stage, and then the friction heat input and the deformation heat input in each stage were calculated. Then the relationship among these heat input values and mechanical properties of welded joints was investigated, and an evaluation value to estimate the joint strength was introduced. Furthermore, the influence of welding factors on the heat input was studied, and possibility to apply the upset burn-off length to a practical evaluation value of joint strength was discussed.

Chapter 1 is an introduction. History, present status, features and problems of the friction welding process are stated, and then the purpose of this study is described.

In Chapter 2, materials, friction welding machine, metallurgical testing method and testing method of joint strength are described.

In Chapter 3, outline of the friction welding process and definition of the heat input in the friction welding is stated.

In Chapter 4, the friction welding experiment of 6061 aluminum alloys was carried out. The heat input which is most suitable for evaluation of joint strength was selected from the relation between the heat inputs and the tensile strength of joints. Result, it was shown clearly that the heat input which is most suitable for evaluation of joint strength is a unit deformation heat input in the upset stage. Furthermore, relationship between the heat input and the burn-off length and between the burn-off length and the tensile strength were studied. Then influence of the mother material diameter on the heat input and the burn-off length was considered.

In Chapter 5, the effect of upset timing in friction welding on the unit deformation heat input in the upset stage was considered. To a certain upset timing, it was shown clearly that the deformation heat input in the upset stage becomes large. Then the heat input was classified into the true heat input and the nominal heat input, and the relationship among these heat input and the burn-off length was investigated.

In Chapter 6, tensile test, bending test, torsion test, fatigue test and Charpy impact test of friction welded joints were performed. And it was shown that it can evaluate by unit deformation heat input in the upset stage and upset burn-off length also about these. Furthermore, the minimum limit heat input and the minimum limit burn-off length to produce the sound welded joints were estimated.

In Chapter 7, the minimum limit heat input and the minimum limit burn-off length of S15CK carbon steel, SUS304 stainless steel, 5056 aluminum alloys, 7075 aluminum alloys and AZ31 magnesium alloy were measured. And such materials also made it clearly that it could evaluate by deformation heat input in the upset stage and upset burn-off length be the same as that of 6061 aluminum alloys.

In Chapter 8, the results of this study are summarized.