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HYUNSEOK YANG[1,2], WOO-CHUL JUNG[1],
MAN-SIK KONG[1*], CHANGHEE LEE[2]

A STUDY ON DRILLING MACHINABILITY OF γ-TiAl ALLOY

Intermetallic γ-TiAl alloy has excellent properties at high temperatures and is thus attracting attention as a substitute for nickel-based superalloy parts for turbine engines. However, γ-TiAl alloy is reported to be a difficult material to be machined due to its low ductility at room temperature, tensile strength, and thermal conductivity. In this study, a system capable of measuring thrust force (T_f) and torque (T_c) during the drilling process was constructed, and drilling processability according to the heat treated microstructure of γ-TiAl alloy was compared. As a result, it was confirmed that the thrust and torque of the γ-TiAl alloy having a microstructure in which the grains were refined by the heat treatment process was relatively low and rapidly stabilized, which is advantageous for drilling.

Keywords: γ-TiAl alloy, Drilling, Machinability, Thrust, Torque

1. Introduction

γ-TiAl alloy is a lightweight material that can be used at temperatures below 800°C and is in the spotlight as a substitute for industrial parts including aircraft and automobile engines made of nickel-based super alloy. Recently, various studies have been conducted to improve the room temperature elongation, which is a disadvantage of the γ-TiAl alloy, or to improve the operating temperature range by adding various alloying elements.

Despite these studies, gamma TiAl alloys are still rarely applied as industrial parts. The reason is that it is difficult to process due to the properties of TiAl alloy with high strength at high temperature, low thermal conductivity, and strong chemical reactivity [1]. Therefore, in recent years, some literatures evaluating and simulating the machining performance of γ-TiAl alloys according to various machining processes have been reported, but the association with the microstructure has not been progressed [2-5]. To improve the elongation at room temperature and strength at high temperature, the γ-TiAl cast alloy requires grain refinement. In this study, the correlation between the drilling performance of TiAl alloy and the TiAl alloy microstructure in which grains were refined by the heat treatment process was investigated.

2. Materials and methods

In order to refine the grains of the γ-TiAl cast alloy having a size of 15×15×130 mm with a composition of Ti-46Al-3Nb-0.5W-0.5Cr-0.3Si-0.2C, cyclic heat treatment was performed as shown in Fig. 1. After the heat treatment, a part of the sample was cut to perform fine polishing, and after etching for 5 seconds with a solution of 15 ml HF, 5 ml HCl, and 80 ml H_2O, microstructure was observed using an optical microscope and SEM. As shown in Fig. 2, a system for evaluating drilling machinability was developed. To compare and analyze the drilling machining performance of the γ-TiAl alloy samples before and after heat treatment, torque (drill rotational force, N·m) and thrust (force applied to the load cell, kgf) data were collected according to machining time. A tungsten carbide tool having a diameter of 3 mm was used for drilling, and the processing was performed to a depth of 6 mm at a speed of 0.1 mm/sec, and the number of drill rotations was maintained at 177 rpm. For lubrication between the drilling tool and the machined surface, compressed air mixed with oil was sprayed to the machined part at a rate of 10 cc/sec using the MQL (Minimal Quantity Lubrication) system. In addition, the samples were polished before drilling to minimize the effect of surface roughness.

1 ADVANCED MATERIALS & PROCESSING CENTER, INSTITUTE FOR ADVANCED ENGINEERING, YONGIN, SOUTH KOREA
2 HANYANG UNIVERSITY, DIVISION OF MATERIALS SCIENCE AND ENGINEERING, SEOUL, SOUTH KOREA

* Corresponding author: mskong@iae.re.kr

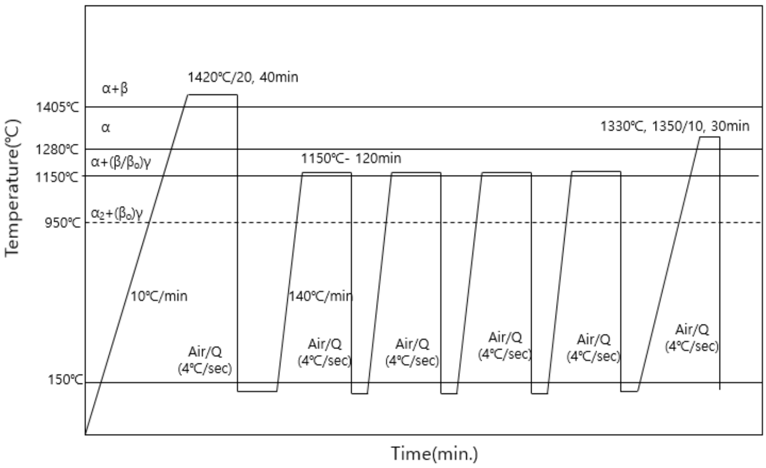

Fig. 1. Heat treatment process of γ-TiAl alloy for grain refinement

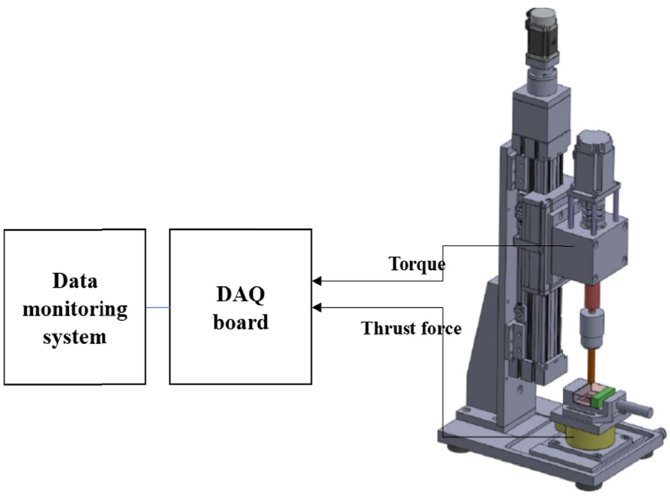

Fig. 2. Machinability evaluation system for drilling process

3. Results and discussion

Fig. 3 shows the microstructure of γ-TiAl cast alloy before and after heat treatment. It can be seen from Fig. 3(a) that a coarse α_2 phase fully lamellar structure with different orientations was observed in the microstructure before heat treatment, and some γ phases existed. As a result of cyclic heat treatment for grain refinement, it was confirmed that grains with $\alpha_2 + \gamma$ nearly lamellar structure of less than 100 um were uniformly distributed within the microstructure as shown in Fig. 3(b). It is known that grain refinement of TiAl alloy occurs due to massive transformation and discontinuous coarsening during cyclic heat treatment [7]. In addition, the nearly lamella structure of TiAl alloy by the cyclic heat treatment process can control the stress concentration phenomenon due to the anisotropy of the fully lamellar structure and is advantageous in improving the room temperature elongation.

Fig. 4 is a graph comparing drill cutting performance for the TiAl alloy in Fig. 3. Torque and thrust measured at 0.01 second intervals rise due to friction and wear between the drill tool and the workpiece in the initial state of drilling, and then form a plateau. As a result of comparing the stabilization start time (processing depth) of the torque during drilling, the TiAl cast alloy with a coarse $\alpha_2 + \gamma$ microstructure starts stabilization from about 26 seconds (processing depth 2.6 mm) as shown in Fig. 4(a). On the other hand, heat treatment TiAl alloy starts to stabilize

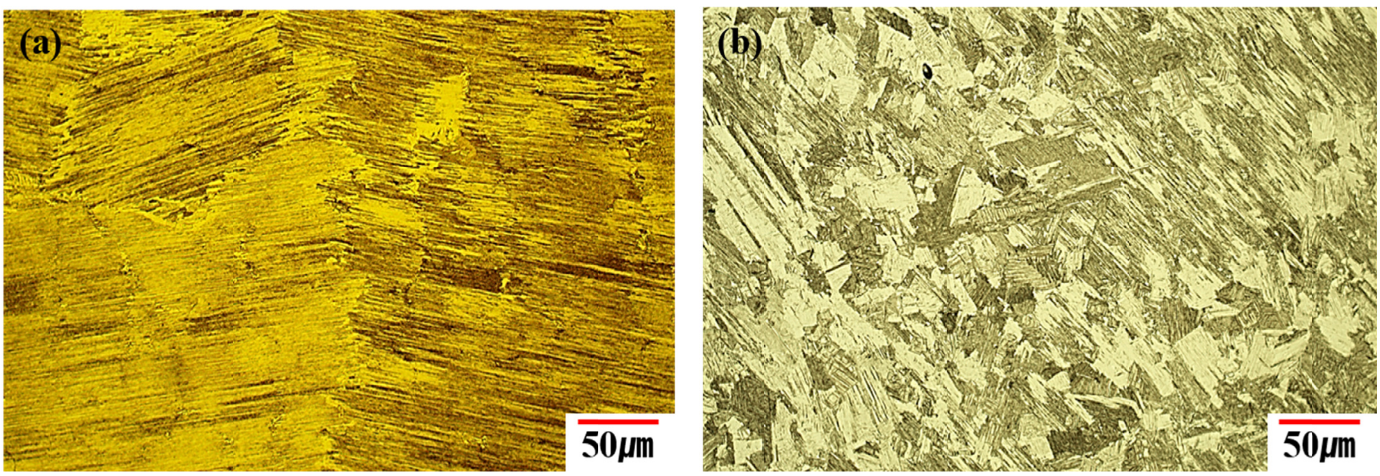

Fig. 3. Optical microstructure of γ-TiAl alloy with (a) as-cast and (b) heat treated samples

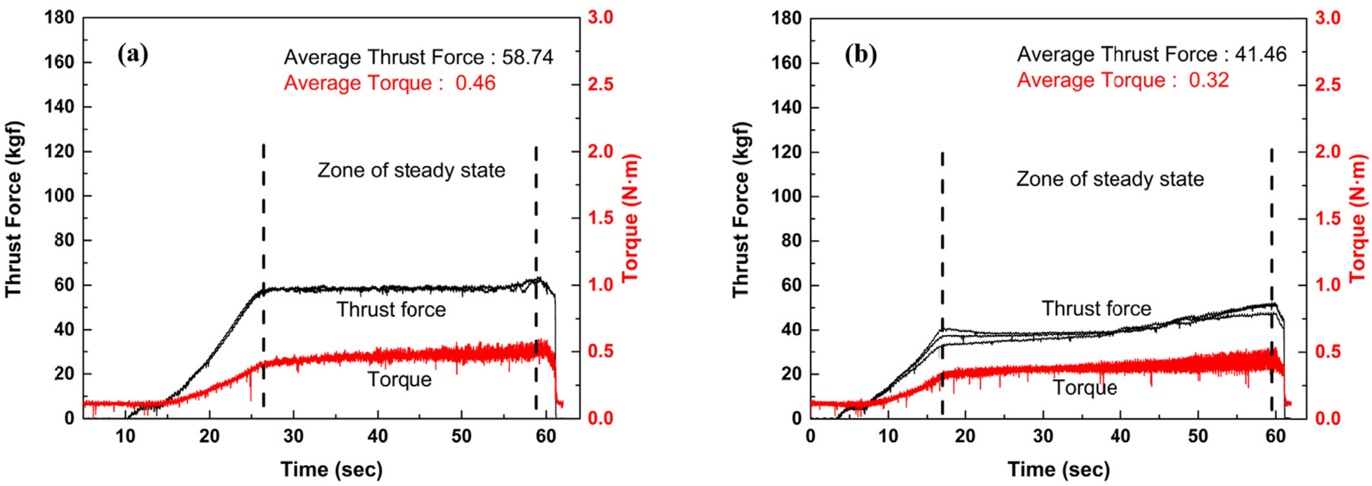

Fig. 4. Comparison of Torque and thrust force of γ-TiAl alloy during drilling process; (a) is as-cast and (b) is cyclic heat-treated samples

relatively quickly from about 17 seconds (processing depth 1.7 mm) as shown in Fig. 4(b). In addition, when comparing the average value of torque and thrust in the stabilization section excluding the rising and ending sections, the heat-treated TiAl alloy is relatively low. It can be determined that grain refinement according to cyclic heat treatment plays a role in improving drill processing performance and tool life.

The chip generated during drilling process in Fig. 5 shows the continuous shear plane of the chip due to plastic deformation It can be observed that the chip width from the heat treatment sample in Fig. 5(b) is relatively larger because the γ phase, which increases the ductility, is created at the α_2 / γ boundary during heat treatment in the lamella structure before heat treatment. Therefore, it can be assumed that the chips are not easily broken during drilling and plastic deformation occurs continuously.

4. Summary

In this study, the drilling characteristics of γ-TiAl alloy according to the microstructure were analyzed. It was found that the formation of fine grains through heat treatment compared to cast alloys having a coarse microstructure can improve the life of the drill tool by lowering the torque and thrust of the tool and stabilizing it quickly. In the future, it is necessary to study the drill workability of γ-TiAl alloy according to drilling tool material, lubricant type, and number of processing, and to analyze the relationship between microstructure and mechanical properties of various γ-TiAl alloys with heat treatment conditions.

Acknowledgments

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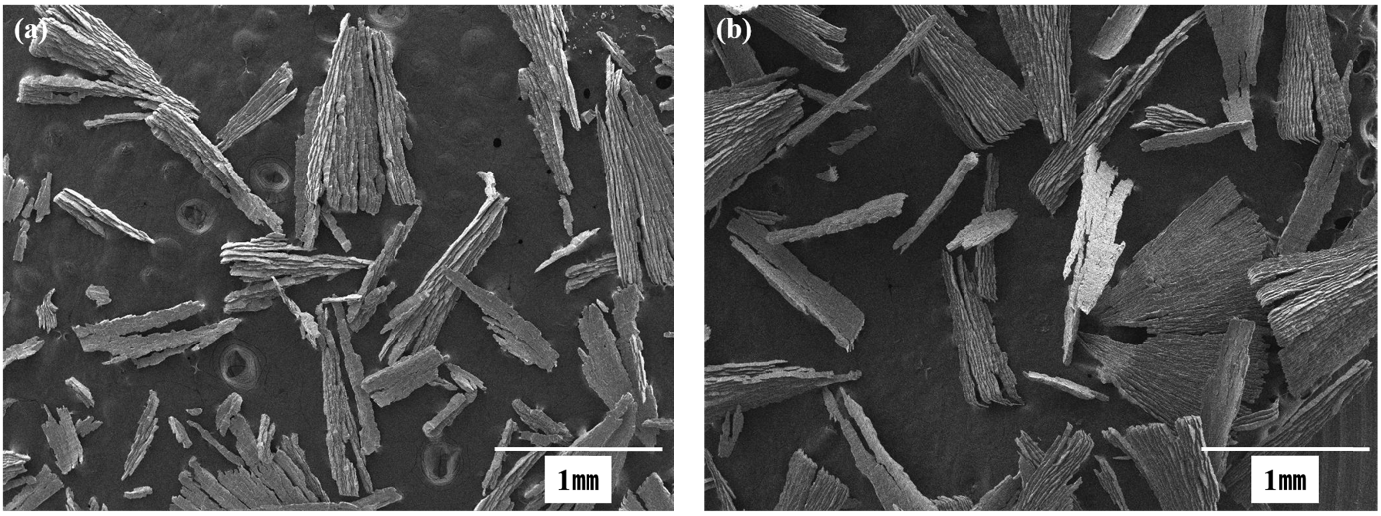

Fig. 5. SEM images of chip of γ-TiAl alloy during drilling process; (a) as-cast and (b) heat treated samples

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