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Evaluation of Axial Flow Impeller Fabrication Process by Wire Arc Additive Manufacturing and Machining †

Shinichiro Ejiri

Nikkiso Co., Ltd., Tokyo 189-8520, Japan; shinichiro.ejiri@nikkiso.co.jp

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Abstract: An evaluation was conducted on the fabrication of an axial flow impeller by a hybrid system of wire arc additive manufacturing and machining. First, a four-bladed stainless steel axial flow impeller was fabricated to measure the number of chips and fabrication time. Next, axial flow impellers with different numbers of blades were designed and compared with those fabricated only by machining from a round bar. In both cases, the number of chips was reduced by approximately 80% by using this system. On the other hand, the increase in the number of blades reduced the difference in fabrication time, which was almost the same with six blades. In conclusion, the use of this system is an option from the viewpoint of reducing environmental impact; however, it is not necessarily advantageous in terms of fabrication time.

Keywords: WAAM; additive manufacturing; turbomachinery; fabrication process; eco-friendly

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1. Introduction

The life cycle energy costs of energy systems can be broadly divided into initial, operational, maintenance, and disposal. Therefore, to realize an eco-friendly energy system for the purpose of a sustainable society, it is necessary to consider not only the energy balance during operation, but also the energy costs, such as during the manufacturing of the components of the system [1]. One of these components is turbomachinery, which is used in thermal and nuclear power generation [2]. These turbomachines are often large machines with special specifications, and if modified into eco-friendly manufacturing processes, the benefits would be significant and of industrial value. Therefore, studies have been conducted on the fabrication of impellers as key components in turbomachinery [3,4]. In addition, the performance of turbomachinery is affected by complex grooves, such as casing processing [5]; thus, improving the use of fabrication technology leads to improved performance. In recent years, studies have been conducted using additive manufacturing (AM) in various industrial applications. Studies have also been conducted on the application of AM from an eco-friendly perspective [6]. Various research and development efforts have been focused on wire arc additive manufacturing (WAAM) because of its compatibility with large and complex-shaped parts [7–9]. Although research results using real industrial parts as test pieces are limited [10–13]. These studies have shown that it is possible to fabricate parts using a fabrication process including WAAM. However, there has been insufficient discussion on the parts for which WAAM should be applied.

The objective of this study was to clarify the value of a fabrication process that includes WAAM as a replacement for the traditional fabrication process. This study was conducted on axial flow impellers used in industrial turbomachinery. In this study, the focus was on the number of blades because impellers can be of various shapes depending on the design specifications [14–16]. First, the axial flow impeller of an industrial pump was fabricated using a hybrid system of WAAM and machining to verify the feasibility of manufacturing using AM technology. Several axial flow impellers were then designed based on the fabricated axial flow impeller and on the information obtained during the fabrication process using the hybrid system; then, a comparison was made with the application of the traditional fabrication process to clarify the advantages of using the hybrid system.

2. Methods

The test model is an axial flow impeller called a fan type inducer, which is used in industrial centrifugal pumps. The impeller outline is shown in Figure 1, and the primary dimensions are listed in Table 1. Fabrication was conducted using a hybrid system of WAAM and machining [12]. A round bar is used as the base material, laminating the near-net shape blades using WAAM. After being laminated by WAAM, the impeller was machined to the designed shape. The base metal and welding wire were general-purpose stainless steel. The measurements were conducted with respect to the number of chips and fabrication time to analyze the fabrication process. The weight of each was measured on a round bar before WAAM, after the completion of the near net shape using WAAM, and after machining. From this difference, the number of chips removed using machining was calculated. The time required for each of the WAAM and fabrication processes is also recorded.

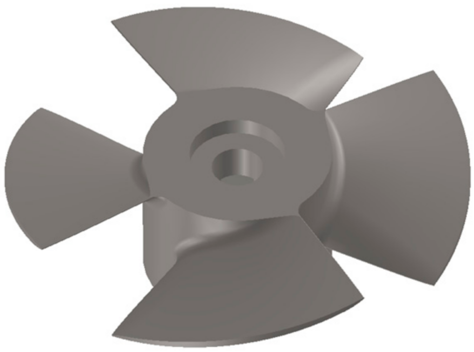


Figure 1. Outline of axial flow impeller.

Table 1. Axial flow impeller specifications.

Number of blades		4
Tip diameter	**[mm]**	125.3
Hub diameter	**[mm]**	51
Hub length	**[mm]**	40

3. Results

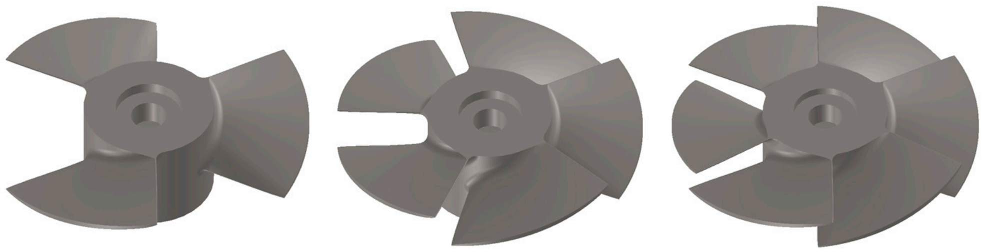
Figure 2 shows the fabrication results of the hybrid system of WAAM and machining. Dimensions were measured by 3D scanning, thereby confirming that the product could be fabricated with a machining accuracy of approximately 0.1 mm. Chip removal volume and fabrication time data were obtained during the fabrication process. The next section in this paper uses these data for discussion.

(a) (b)

Figure 2. Fabrication of the axial flow impeller: (**a**) near net shape blades prepared using WAAM; (**b**) finished axial flow impeller.

4. Discussion

Several axial flow impellers were designed based on the fabrication impeller. In this study, we focus on the number of blades. The designed impellers are shown in Figure 3. The shape of the impeller was the same as that of the fabricated impeller, except for the number of blades.



(a) (b) (c)

Figure 3. Redesigned axial flow impellers: (**a**) three blades; (**b**) five blades; and (**c**) six blades.

Chip volume from the WAAM and machining process obtained during the fabrication of the impeller in Section 3 will be analyzed as one. Here, it is assumed that the parts are fabricated in extremely small quantities. The object of comparison is assumed to be 130 mm in diameter and 70 mm in length (workpiece 40 mm, gripping allowance 30 mm is the same as WAAM and machining process), fabricated only using machining from a round bar. The comparison results are shown in Figure 4. As the number of blades increased, the volume of chips produced using WAAM and machining tended to increase, while the volume of chips by machining only tended to decrease. However, regardless of the number of impeller blades, the chip volume was clearly lower with the WAAM and machining process than with machining only. This indicates that fabrication using the WAAM and machining process is an eco-friendly option.

For additional analysis, compare the machining times for the same fabrication process. As in the chip volume comparison, the analysis was based on data obtained during the fabrication of the impeller in Section 3. Here, the lamination time per blade using WAAM is treated as one. Figure 5 shows the results of comparing the fabrication time for each number of blades. It can be confirmed that the fabrication process using the WAAM and machining process takes less time for up to five blades; however, it can also be confirmed that the fabrication process for six blades takes about the same amount of time as when it is fabricated using machining only. To clarify the cause of this behavior, a breakdown of each fabrication process time was analyzed. Figure 6 shows the breakdown of the fabrication time using WAAM and machining, while Figure 7 shows the breakdown of the fabrication time using machining only. The fabrication time using WAAM increases as the number of blades increases, whereas the roughing time for fabrication using machining only tends to decrease as the number of blades increases. Most of the fabrication process in each case is due to finishing machining. Therefore, even if the number of blades was further increased, no significant difference in the fabrication time was observed between the two methods. Hence, if the number of blades is reduced, it is possible to reduce the fabrication time by utilizing WAAM; however, if the number of blades increases, it is more advantageous to fabricate it using machining only. Nevertheless, the roughing time in this study was relatively short because a general-purpose stainless steel was used. If difficult-to-machine materials were used, the roughing time would be significantly longer than in this case. This topic is a subject for future work in this area of study.

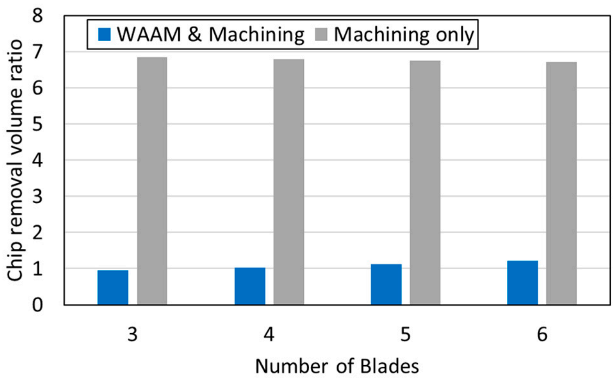


Figure 4. Chip removal volume of axial flow impellers with different numbers of blades.

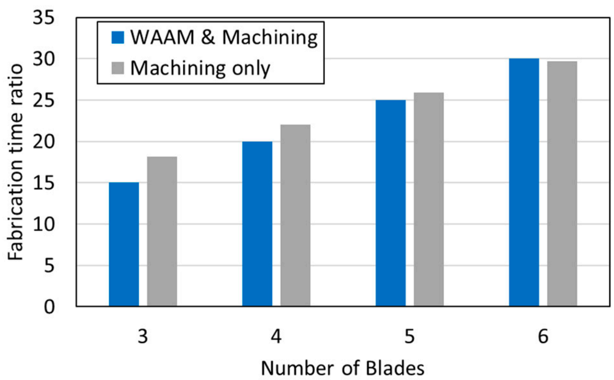


Figure 5. Fabrication time of axial flow impellers with different numbers of blades.

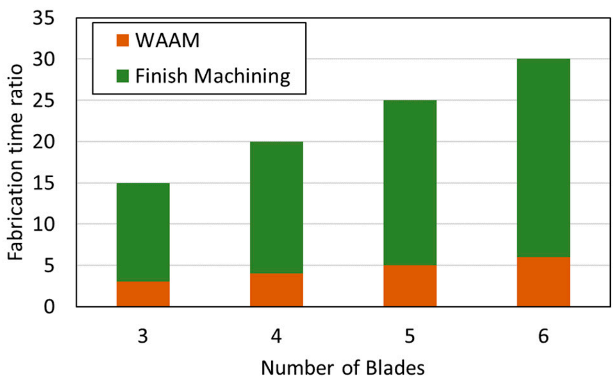


Figure 6. Fabrication time at the WAAM and machining processes of axial flow impellers with different numbers of blades.

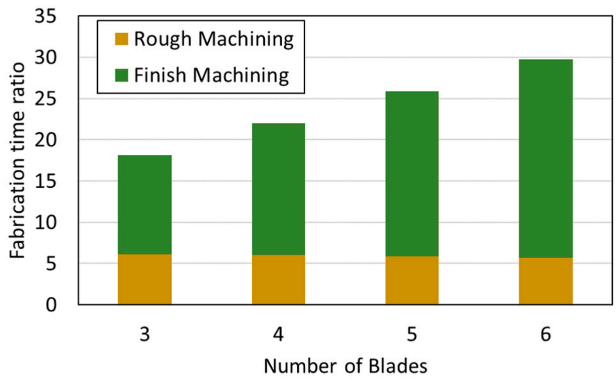


Figure 7. Fabrication time in the machining-only process from the round bar of axial flow impellers with different numbers of blades.

5. Conclusions

In this study, to clarify the value of the fabrication process that includes WAAM in replacing the traditional fabrication process, an evaluation of the fabrication process was conducted using a hybrid system with WAAM and machining. The results of these measurements were compared with those obtained using the traditional fabrication process, in which impellers are fabricated from a round bar by machining only, to clarify the advantages of this proposed hybrid system.

It can be expected that the use of WAAM for parts of fabrication will reduce the chip volume to a greater extent than if the parts were fabricated using machining only. In the case of the 3–6-bladed axial flow impeller used in this study, the volume of chips can be reduced from 82% to 86% from the machining-only process. On the other hand, the fabrication process using WAAM does not necessarily require shorter fabrication times than traditional machining-only processes. In the axial flow impeller in this study, the use of WAAM is advantageous when the number of blades is small; however, the machining times of the WAAM and machining fabrication process and the machining-only fabrication process are almost the same when the number of blades is six. According to the two evaluation indices of chip volume reduction and machining time reduction, the three-bladed impeller with the lowest number of blades was the most suitable for the fabrication process using this hybrid system among the impellers used in this study.

It was concluded that this hybrid system is an eco-friendly fabrication process because it can significantly reduce chip emissions. The fabrication time is similar to or slightly shorter than the traditional machining-only process, which is not a significant disadvantage, making the WAAM-based fabrication process an option for developing a society with low environmental impact.

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